



V8 AERO ENGINE

V8 Fourstroke Aero Engine

Eric Whittle

introduces his 10.6cc air cooled aero engine with glow plug ignition and commences construction with step-by-step details of the crank case.

Part 1

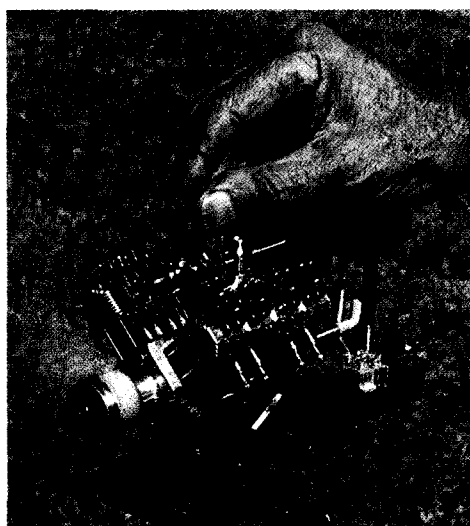
Eric Whittle, that's his hand, demonstrates his engine at the Old Warden Scale Weekend last summer. Onlookers were impressed by the ease with which the V8 started and the sweetness of its running. The 1995 Scale Weekend at Old Warden is scheduled for 10-11 June.

Introduction.

V8 aero engines seem to have been a phenomenon of the early years of aviation. Examples, most of which seem to have been liquid cooled, were around before and during the first world war. There were some air cooled V8s—Renault and Curtis were but two manufacturers of the early years. Airdisco also made a 200HP air cooled V8—an example of which is to be seen in the DH 51 biplane in the Shuttleworth Collection at Old Warden. This is the engine which our miniature most closely resembles.

Miniature or working model air cooled V8s also seem to be thin on the ground. The only model V8s of which I know are liquid cooled automobile type engines in the larger scales, i.e. 1/5-1/3. Very small miniatures of either type of V8 seem not to have been contemplated by model engineers or other builders to date and it seemed to me that a really miniature V8 was just crying out to be made. I had already developed and built two very successful 5.3cc in-line 4-cylinder glow plug 4-stroke engines which had proved to be practical power units in a model aircraft, so why not use the same design in a V8 configuration? There was bound to be some slight power to weight advantage over the in-line 4-cylinder engines. There would be one or two small problems to solve but nothing that could not be overcome.

My engine took six months to make from start of construction to its first run on a 12 x 6in. propeller. It is an easy starter—it could hardly fail to be with all those cylinders! Maximum speed to date (approximately one hour's total running) is 7000rpm with a 12 x 6in. propeller, idling speed is 2500rpm. This is when you realise you



have a V8 for, at this speed, the engine is as smooth as silk and just purrs.

For miniature engineering enthusiasts, the dimensions are as follows. Overall length is 4-1/2in. width over exhaust pipes is 3-1/4in. and height is 3-1/88 inches. All-up weight is 15 ounces. The engine contains 550 components, over 280 of which are moving parts. The equipment used to make the V8 was a Myford Super 7 with a VMA milling attachment, a 4in. rotary table and a set of 10mm Pultra collets in a home made collet spindle adapter. A bench drill, propane gas and the usual hand tools complete the list. Commercial items worked out to be 8 glow plugs, 3 ball races and the 2 timing gears.

At this point I must warn would-be builders that although the V8 is a straightforward engine to build and no special skills are required for any part of its construction, a huge amount of patience will be required to complete the engine to the running stage. It is most definitely not for the builder who is in any sort of a hurry. I shall assume that any reader who intends to have a go at the mini V8 will have sufficient machining experience to build it from my drawings without too much interference from me. Where appropriate, I shall describe the methods which I used for the various jobs and operations. This is not to say that my methods are either the best or the only ones, but they worked for me and will get the job done.

Before we go any further, a list of materials required and their suppliers may be helpful.

Crank case halves, front bearing housing and rear gearbox housing 6in. x 2in. dia. HE30 aluminium alloy.

Cylinders and crankshaft 18in x 1in. dia. EN 16T steel.

Pistons and connecting rods 12in x 1/2 x 1/2in. HE15 aluminium alloy.

Cylinder heads 6in. x 1in. dia. HE30.

All the above materials are avail-

able from Woking Precision Models, 10 New Street, Oundle. Peterborough PE8 4EA; tel: 0832-272868.

Big end bearing shells, 0.005in. bronze shim available from Kirjeng M.E Services, 17 Gables Lea, Sutton Bonnington, Leicestershire LE12 5NW tel: 0509-672025. Timing gears, 48DP 1 x 18T. 1 x 36T steel spur gears, part numbers PG48-18 and PG48-36, from Hinchliffe Precision Components Ltd., Storforth Lane Trading Estate, Chesterfield S41 0QZ tel: 0246-209683.

Crankshaft ball races, 3 x sealed ball races 13mm OD x 6mm ID x 5mm wide, will be obtainable

from local bearing stockist.

8 x ENYA 3 glow plugs will be needed when the engine is nearing completion.

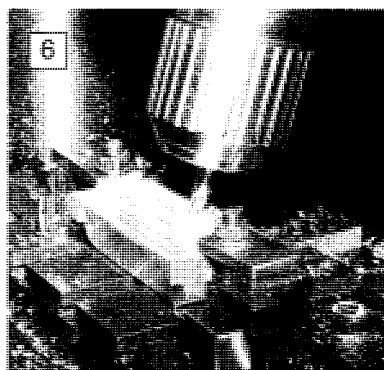
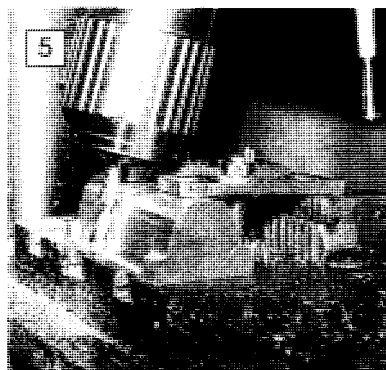
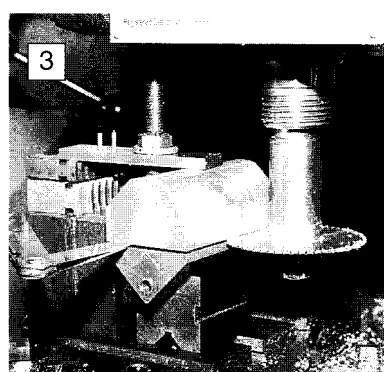
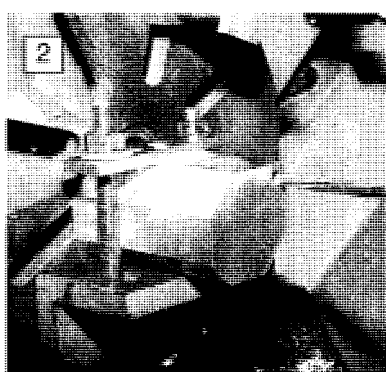
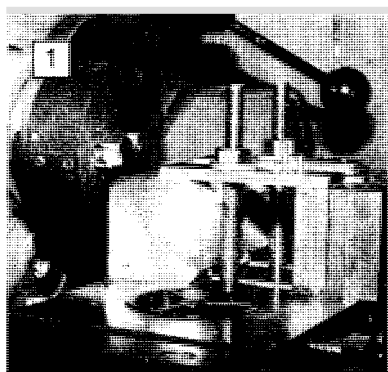
The rest of the material is various sizes of mild steel including 18in of 1/4in stainless steel, 6in of 3/16in OD copper tube and some 8, 10 and 12BA steel screws and nuts, all available from most model engineering suppliers and advertisers. Most of the screws and nuts used are non-standard, i.e. smaller heads on screws and nuts drilled and tapped the next even BA number size up. This makes for a neatly fitted engine and is a must if you want to exhibit or demonstrate the engine on completion. The manufacture of suitable box spanners (nut spinners) will be dealt with later in the construction notes.

Photographs will be used to show operational set-ups where this is likely to be helpful but drawings will be used when the parts are too small to be photographed.

Crankcase

The 6in. chunk of 2in dia. HE30 alloy will be ample to make the entire crankcase and front and rear bearing housing. To start we need to saw or part off a piece 3in. long which will make both upper and lower case halves. Both ends should be faced smooth. Fit the 4-jaw chuck and face the piece to form a square bar 3 x 1-5/8 x 1-5/8in. The corners will not clean up at these dimensions but this won't matter too much. What we should aim for is to get one corner with a 1/8in. wide unmachined section for the length of the work piece, then to equalise the three remaining unmachined widths to leave the work-piece nominally 1-5/8in. square. The corner with the narrowest i.e. 1/8in. width will be the top of the crankcase.

Now the cylinder mounting faces can be machined. These must, of course, finish up at 90deg. to one other, easily achieved by fly cutting. If the work is clamped to the boring table and truly aligned, 0.020in. can be removed



1: Work on the crankcase is commenced by flycutting a 3in. length of 2in dia. HE30 light alloy to produce a bar 1-5/8in. square.

2: Carefully marked out and set up, the camshaft bore is accurately positioned with respect to the crankshaft position, centred, drilled and reamed to size.

3: Top and bottom halves of the crankcase are separated by the use of a slitting saw. The use of a Vee-block provide good support to the embryo crankcase and feeler gauges prevent the clamping force from closing the earlier sawcut.

4: Carefully gripped and gently cut, the sawcut top crankcase half surface is cleaned up by milling.

5: A ball nose slot drill and careful milling with the milling head set over to 17-1/2. deg. is necessary for profiling the bottom crankcase half.

6: Some of the scrap material inside the crankcase is removed by drilling before profiling the interior of the lower crankcase half.

from one of the sides which forms the narrowest corner width. The work is then reclamped on the newly fly cut surface, i.e. surface to boring table, and the other face fly cut. This will leave the unmachined corner width at about 0.093in (see **photo 1**) These fly cut surfaces are the final finishes so take care of them from now on.

While set up for flycutting, the length of the work piece can be finalised by fly cutting both ends to the dimensions shown on the drawing. We now have two nice faces on which to mark out for the position of the crankshaft and camshaft centres. The crankshaft position must first be located and marked, easily done by scribing a line 0.60in. from and parallel to each of the cylinder mounting faces, as seen from the end of the workpiece. The distance from the crankshaft centre to the two cylinder mounting faces is 0.60 inch. I used my scribing block on a surface plate and, with the aid of an eyeglass set the scriber point to 0.60in. above the surface plate against a steel rule. Put the workpiece on the plate. cylinder mounting face in contact with the plate. lightly scribe a line and repeat on the second cylinder mounting face. The intersection of the two lines is the crankshaft centre and can be marked with a sharp scriber point. All this should be repeated on the other end of the workpiece and, while you're at it, also scribe a light centre line along each cylinder mounting face.

The workpiece can now be machined to the final overall width of 1.5in., the dimension across the engine mounting

pads. So, if a mark is scribed 0.75in. either side of the crankshaft centre, the width will be established. Now sit the workpiece upside down in the Vee of a Vee-block on the surface plate and, with the aid of an engineer's square, scribe firm lines through the two width marks and a light line through the crankshaft centre mark., The work can now be set in the 4-jaw chuck and faced to finish by eye at the width line. As the width line is approached with the tool, any lack of truth in work, setting in the chuck will become apparent and adjustments may be made to suit. Repeat for the other side. Needless to say, smooth faced packing pieces should be inserted between work and chuck jaws.

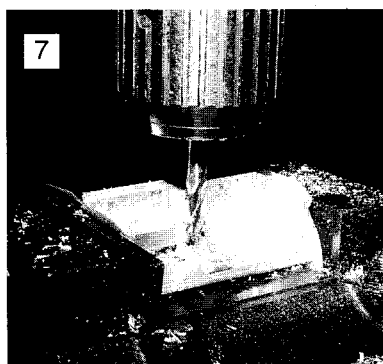
The next job is positioning, drilling and reaming for the camshaft which has three journals, front centre and rear. all three of which can be dealt with by drilling and reaming one hole right through the workpiece at this stage of machining. This hole must, of course, finish up in the right place! The Hinchliffe gear data specifies that the centre distance of the two gears should be 0.5625in. to give about 0.004in. of play or backlash. This proved to be as near correct as I can measure on my own prototype engine, so 0.5625in. is what it must be. Other builders may have different methods for precise positioning of the camshaft centre, but the following is how I did it. There is already a crankshaft centre mark through which passes a light vertically scribed line. The camshaft will be positioned on this line 0.5625in. above the Crankshaft centre.

The workpiece is held vertically in the machine vice on the milling table, in my case on the lathe boring table as I used the VMA milling attachment.

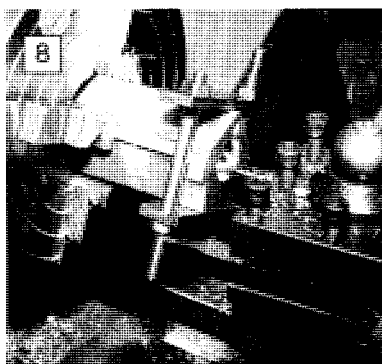
The vertical line passing through the crankshaft centre is then aligned dead true by adjustment of the cross slide, and the vice secured to the boring table. I fitted a concentric 60deg centre made from 1/8in. dia. silver steel into the vertical mill head collet. The point of this centre is then positioned exactly into the crankshaft centre mark and the cross slide feed dial set to zero. Then, taking account of feed screw free play (backlash), the slide should be moved in the appropriate direction for 0.5625in. and the 60deg. centre piece is brought down to make a small centre inmark in the proper place on the vertical line. The work can now be set up on a face plate in the lathe and the camshaft centre inmark accurately centred using a centre finder and DTI. Centre drill, drill and ream 7/32 inch. Drill carefully, using a new or accurately ground drill to minimise run-out over the length of the work. Run-out shouldn't be too much of a problem anyway since it will be confined to one end of the case which will be the front end. Be sure to identify the accurately marked out gear end of the work. I could not detect any run-out when I checked my own workpiece. **Photograph 2** shows the reamer in use. Use backgear and cutting fluid and clear the chips frequently.

The next job is to separate the work piece into the top and bottom halves of the crankcase. It is desirable to maintain both crankshaft centre marks in the ends of the

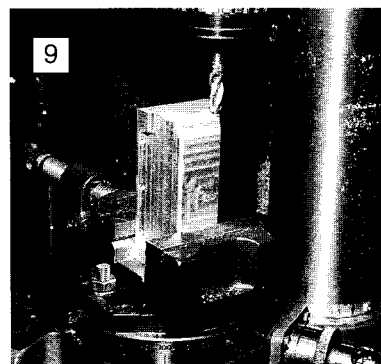
7: Chambers on the mating face of the top crankcase half are carefully prepared by milling with a 1/4in. slot drill.



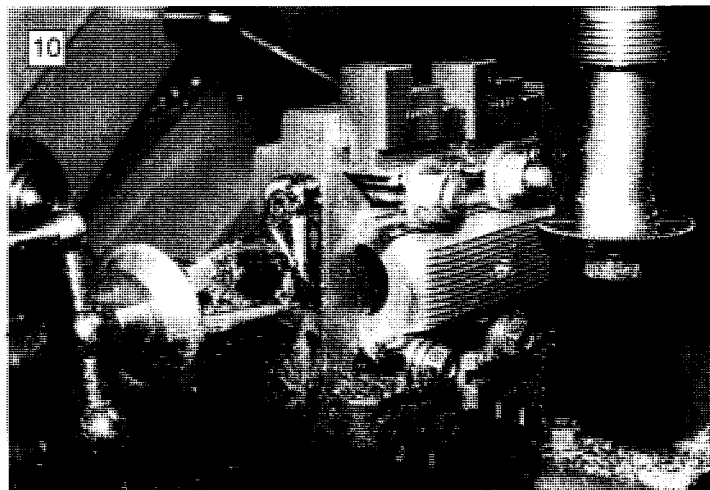
8: Bearing housings are bored to size with the two crankcase halves assembled and held in the 4-jaw chuck.



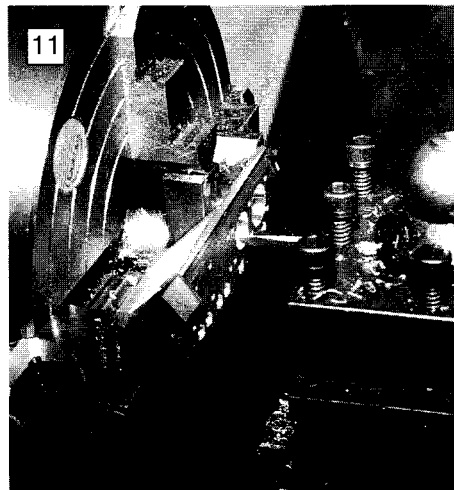
9: Once the bearing housings are finished, the end profiles of the crankcase are produced with the aid of a ball nosed cutter and small rotary table.



10: Eleven 0.040in. slots are required underneath the bottom crankcase half. Great care is necessary to ensure that the slits are centralised and to avoid cuffing right through the wall.



11: The Author bored the angled faces of the top crankcase half by careful setting in the 4-jaw chuck in the lathe. Other builders may prefer to bore these positions in the vertical milling machine.



workpiece since this will facilitate accurate centring and machining later of the two halves, which means that the work piece must be sawn or parted 1/32in. below the centre line to leave the centre marks intact. The method I used to part the work piece into upper and lower halves is shown in photo 3. In my case, the saw diameter was just not quite big enough and an uncut strip was left up the centre of the work which had to be sawn by hand afterwards. This didn't really matter since the top half mating face was finished with a skimming cut anyway, see **photo 4**.

The cut must be light enough to preserve the two centre marks on the end faces, therefore the work piece should be set quite accurately in the machine vice, otherwise one or both centre marks could be lost. Machining the mating face to some 0.025in. below the crankshaft centres means, of course, that the mating surfaces of the top and bottom halves of the assembled crankcase will not be exactly on the engine centre line, but this will not be noticed in the fit of the two halves. The important thing is that there will be a full centre pop mark on which to accurately centre when you come later to bore the ends of the assembled case. These bores must be true to maintain the 0.5625in. centre distance between crankshaft and camshaft to suit the timing gears.

The mating face flanges should be machined next. Study of the upper case half drawing reveals a flange depth of

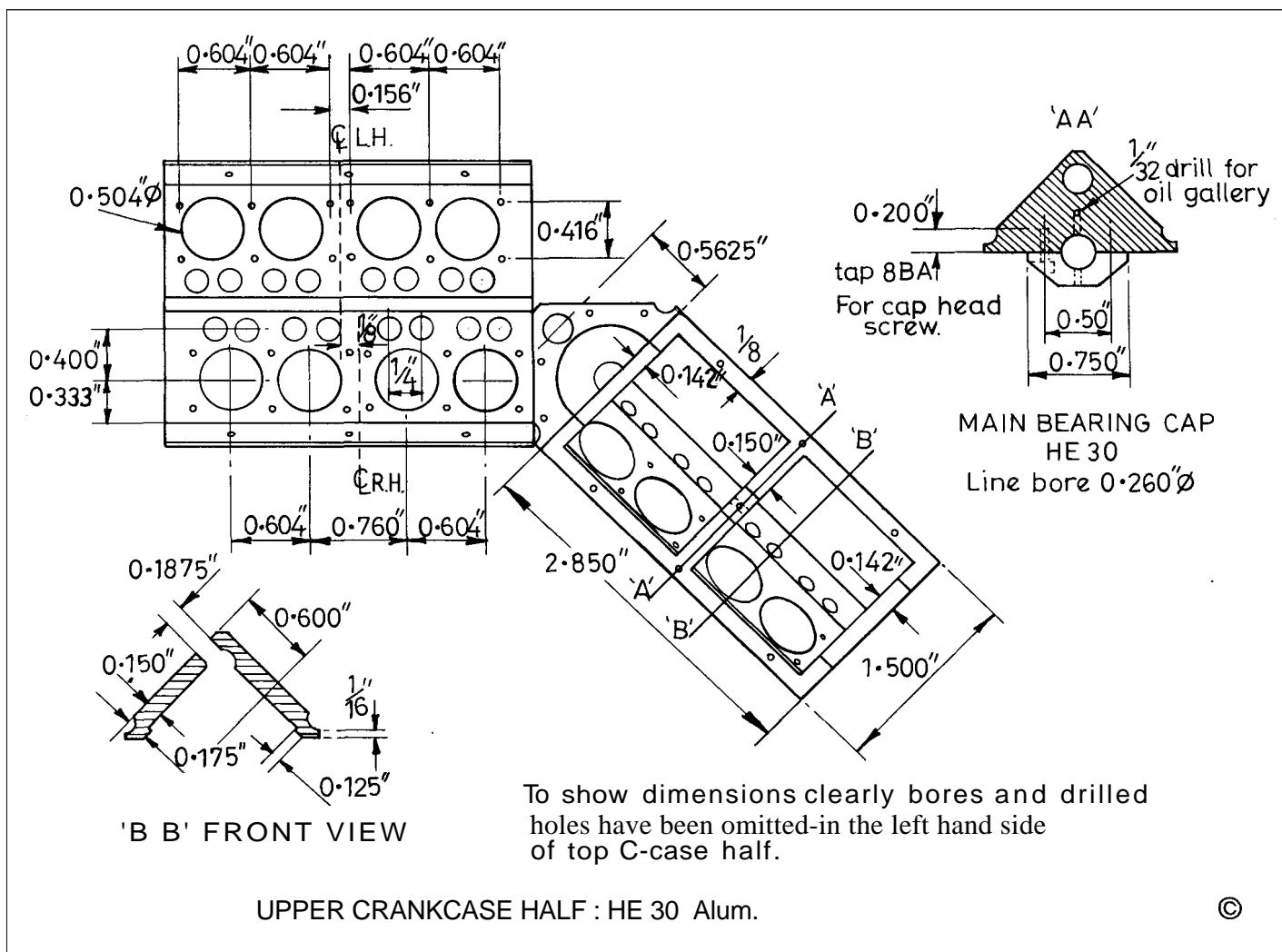
1/16in. leaving the cylinder mounting face 0.333in. wide from the cylinder mounting face centre line. This operation is conveniently done with a 1/4in diameter ball nosed milling cutter. If the top case half is clamped to the mill table and truly aligned, the flanges can be formed with the ball nosed cutter until their depth is 1/16in and the cylinder mounting face is 0.333in. wide from the centre line. Repeat for the other side.

While the milling set up is still available, the bottom half of the crankcase can be machined to produce the lower mating flange. The side of the lower case half will have to be profiled for this which will also form the engine mounting pads. Start by taking a light cleaning cut, holding the lower half mating face in the machine vice. Reverse or invert in the vice and machine the bottom surface to the 0.940in. dimension shown on the drawing. Now clamp the work mating face down and truly aligned, set the mill head over to an angle of 17-1/2deg. and fit a ball nosed end mill in the mill head collet. Touch the nearest top corner of the work piece with the flank of the end mill and either set the feed screw to zero or make a note of its reading since the cutter should be advanced about 0.200in. in many light cuts to produce the required profile. **Photograph 5** gives a good idea of what I mean. The cutter should only be taken to the top surfaces of the mounting pads which are really

the bottom surfaces since the case half is being held upside down. All dimensions are shown on the drawing. When you have cut back for 0.200in. start work on the remaining material between the mounting pads. Cut down to finish with a flange thickness of 1/16in. and keep an eye on the widths of the pads. Their height and width is not critical, but they need to finish by looking identical.

When the other side has been machined in the same way, the lower case should have a bottom width of about 0.900in. and a flange-to-side-wall dimension of about 0.120in. as shown on the drawing. While the mill head is set at the appropriate angle, it may be as well to machine out the inside of the bottom half. To facilitate this operation much of the material can be removed by first drilling a number of holes in the work, as seen in photo 6. The holes should be drilled using the bench drill. The work is then returned to the milling machine and clamped for milling. Align true and machine one half of the case to a wall thickness of 0.050 inch. Turn the work through 180deg., reclamp and align and complete the other half, taking care to get the depth and end measurements right. Check the drawing. It would be so easy to go through the side or bottom if you got it slightly wrong. Remember that the bottom of the case is to be fluted later.

The top half of the case can be machined out next. First clearly mark



with deeply scribed lines the two chamber areas on the mating face. The case half can then be set in the machine vice as shown in **photo 7** and truly aligned. Milling can be completed with an ordinary 1/4in diameter end mill, and should be taken up to the scribed lines in both chamber areas, initially leaving both cylinder mounting faces 0.175in. thick. The inner area is then reduced by a further 0.025in. to a thickness of 0.150in. leaving a 1/8in wide strip of 0.175in. thickness at the mating flange. This ensures sufficient flange width to accommodate the 10BA fixing screws.

Turn the work piece through 90deg to machine the other side in the same way and to mill out the 1/8in radius left in the corners during the first operation. These operations will break through into the camshaft gallery in the top corner of the case.

The next task will be joining the two case halves by the flanges. This job is slightly tricky since we are dealing with drilling small holes in curved surfaces which is best done by spot facing first. Since I wanted to screw from underneath, as in most full sized engines, I was stuck with having to spot face the lower half flanges. Owing to the depth of the lower case and the close proximity of the case wall it was necessary to grind the shank of a 3/32in end mill to a diameter which allowed the flange to be spot faced

without fouling the case wall.

For the actual job, align and clamp the case half onto the mill table and mark the three screw positions on the flange. The spacing is not critical but needs to look right. The edge of the 3/32in. spot face diameter must be exactly 0.020in from the edge of the flange. Feed the cutter down slowly to just give a full circular face then replace the cutter with a 1/8in centre drill and centre for a depth of 1/16 inch. Make sure that you don't drill into your machine table! When all six positions have been similarly started, the work can be transferred to the bench drill and all six places drilled 10BA tapping diameter.

Clamp the two halves together with a tool-maker's clamp and align all four faces or edges carefully. Drill through the upper case half with the 10BA tapping drill, remove the clamp and drill the lower case holes No.50 for 10BA clearance, tap the upper case holes 10BA and fit the two halves together with six 10BA cheese head screws whose heads have been reduced to 0.090in diameter.

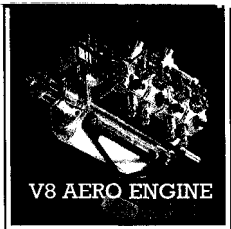
Drill and bore the case ends to accommodate the front and rear bearing housings. Set the crankcase in the 4-jaw chuck as shown in, centring the centre mark with a DTI. Centre drill, drill through 3/8in dia. and bore to 0.833in dia. Repeat these operations on the other end.

The ends of the lower case can now be cut back as shown on the drawing. The easiest way to do this is to use a rotary table. If the rotary table is accurately centred under the mill head, the work can be held upright in a machine vice on the rotary table and the crankshaft centre position then set true with the mill head. The machine vice is then secured to the rotary table. The crankshaft centre position will not be marked on the workpiece but you should have little difficulty in locating it nearly enough. One way is to turn a piece of scrap to 0.833in diameter, press it into the half of scrap of the case half and centre the pip under the mill head.

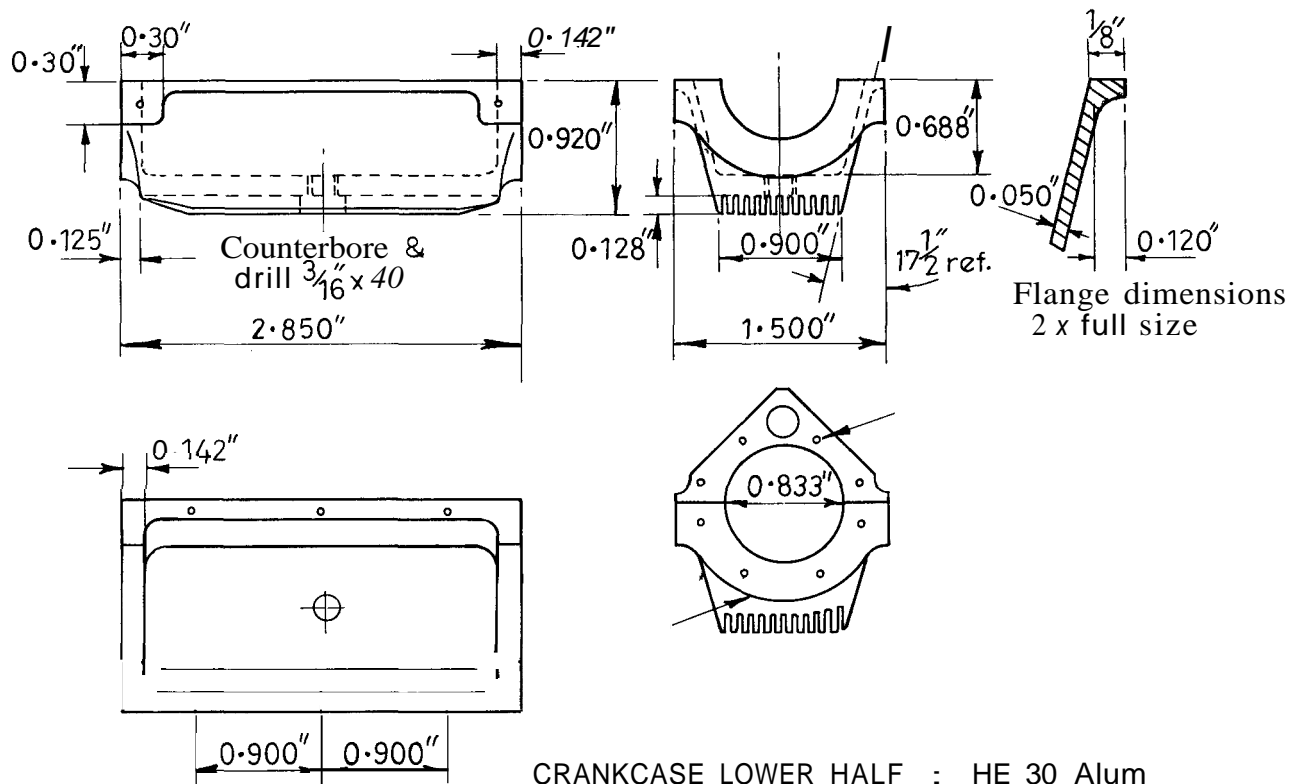
Milling is done with a 1/4in diameter ball nosed end mill to the drawn dimensions. **Photograph 9** shows this operation, the rotary milling here having been done before the ends of the case were bored. This was my error since the case ends should have been bored first.

The bottom of the lower half case can now be fluted. Eleven 0.040in flutes are required and care is needed to get them in the middle of the bottom surface. Special care is needed not to break through the bottom front corner where some of the flutes are extended up the front of the case. **Photograph 10** shows my set up for cutting these flutes.

The remaining machining on the lower case half is drilling and tapping the oil drain hole and



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©

the 6BA mounting pad holes. The drain hole is best machined on the milling table by clamping and counter boring to the bottoms of the flutes with a 9/32in end mill then drilling and tapping 3/16in x 40TPI.

When all the machining has been done the bottom half can be filed, scraped, emery papered and polished up to the standard of a miniature casting.

To complete work on the crankcase halves, all the holes must now be positioned, drilled, bored and tapped for the 8 cylinders, 16 cam follower guides and 24 cylinder head fixing screws 48 holes in all and they must all be in the right place! First study the drawing which shows that the left and right hand banks of cylinder bores are 1/8in out of line lengthways, so be very careful with the initial marking out of the two cylinder mounting faces.

There should already be a fine scribed line along the centre of each cylinder mounting face. Set the point of your block scriber to exactly half the length of the case half. This will be 1.425in or close to it. Now stand the upper case on end on the surface plate and scribe a light line across the width of both faces. This line will be the middle of the engine so the true middle for the right hand or starboard bank of cylinders must be 1/16in forward of this line, and conversely the left hand or port bank of cylinders must be 1/16in rearward of the line, i.e. the right hand bank as seen from the rear of the engine must be 1/8in forward of the left hand bank.

So, if a small centre mark is made in the correct

position on each cylinder mounting face all will be ready for setting up to machine the holes. Set the workpiece in the machine vice, gripping across the ends. Align dead true in all planes and centre the appropriate centre mark under the mill head. Taking due account of free play in the feed screw, move the work back for 0.984in to set the first position or the first cylinder centre under the mill head. Still taking account of free play, set the feed screw dial to zero ready for moving to cylinder centres 2, 3 and 4. This zero position will be the reference point for all 24 hole centres.

Now centre drill No. 1 cylinder position then move 0.604in for No. 2, 0.760in for No. 3 and 0.604in for No. 4. The job will be easier and quicker if a note is made of the feed screw dial readings for each position. Return to zero and drill all four positions with a 7/16in dia. drill then, using a boring head, bore each hole to a diameter of 0.504 inch. I have no boring head so had to set up at each cylinder position in the 4-jaw chuck and bore to size after the rest of the holes had been machined under the mill head (see photo 11).

After boring, or in my case just centre drilling the four cylinder positions, return to zero ready for drilling the 12 fixing screw holes. The drawing shows these to be placed 0.208in either side of the cylinder centre line, so a reference reading must be taken for moving sideways from the centre line. Free play must be accounted for again. First move to a position 0.302in forward of the first cylinder centre then move sideways

for 0.208 inch. The order doesn't matter. This is the position of the first fixing screw hole in that row of six. Centre drill that position and move 0.604in to No. 2, 0.604in to No. 3, 0.156in. to No. 4, 0.604in to No. 5, and 0.604in to No. 6. Make a note of the dial reading for each position, return to the first position and drill No. 50 for 8BA tapping. Repeat on the other five centres. Return to the first position and tap by hand using the mill head collet to guide the tap. Repeat on five more holes. Now move over 0.416in for the other row of six holes and repeat the operations.

The 8 cam follower guide holes can now be drilled and reamed. Their position is 0.400in. from the cylinder centre line and each pair is in line with its cylinder centre. The positioning movements are easily determined from the drawing. Centre drill, drill and ream each position. The drilling and reaming requires some care since you must not go much beyond the halfway position of the 7/32in diameter of the camshaft gallery. A machine reamer should be used for this job since a hand reamer will not ream a full diameter at that restricted depth. Check with the top half cross-section drawing. The second cylinder mounting face is now set up and all the operations repeated. From the second centre mark which will, of course, be 1/8in. out of line lengthways from the first mark. Needless to say, the crankcase so far represents a great deal of work so take your time, check the drawing. Don't scrap it!

To be continued

Fourstroke Aero Engine

Eric Whittle

continues his description of the construction of his 10.6cc air cooled aero engine with details of the bearing housings.

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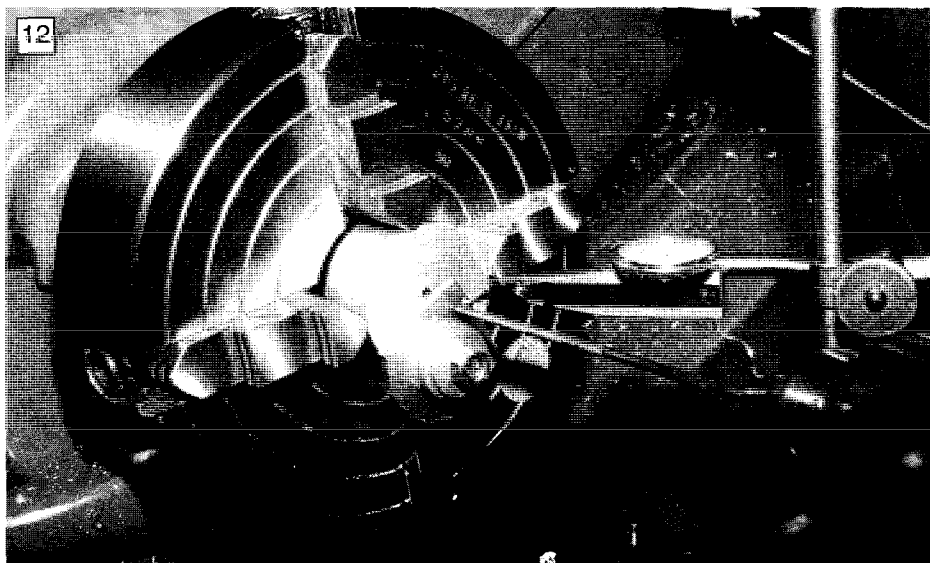
Front bearing housings

The front bearing housing is made from a piece of HE30 aluminium alloy. If a piece about 1 in. long is sawn or parted from the remainder of the 6in. bar, more than enough will remain for the rear bearing housing and the gear case cover. If everything goes right there should also be sufficient for the two carburettors to be made later on.

The front housing is a fairly straightforward turning job. Hold the workpiece in the 3-jaw chuck and start by facing, centre drilling and drilling through 7/32in. diameter. The bearing seats should be bored to 13mm dia. for a depth of 0.388 inch. The final cut should be taken carefully so that the ball races are a hand push fit into the bore. Anything more than a hand push fit will make life difficult later in the construction process when it is necessary to dismantle and re-assemble the components to fit the crankshaft and connecting rods.

The remainder of the 7/32in. dia. drilled hole is next bored to 0.238in. dia. to provide 0.002in. clearance on the 6mm diameter at the front end of the crankshaft. Turn the 0.833in. register diameter before removing the front housing from the chuck. This too should be a hand push fit into the front end of the crankcase for a depth of 0.142 inch.

The workpiece should now be reversed in the chuck and held on the 0.833in. register to turn the front of the housing to the profile and dimensions shown on the drawing. It can then be profiled to its 'frontal' shape. Fit the workpiece into the front of the crankcase and scribe the profile of the case onto the rear of the housing flange. The two straight sections can be sawn and filed to the scribed lines and finished to the level of the cylinder mounting faces. Use needle files and emery paper but be careful not to mark or deface the cylinder mounting faces themselves. The bottom half profile should be machined to match the radius on the lower half of the crankcase. I machined mine using a rotary table to produce the radius, having first made a mild steel spigot to a snug fit in both rotary table and ball race seat to locate the housing centrally on the table.



12: Setting the front bearing housing to bore for the camshaft front bearing. Note the use of the 2in. steel disc fixture for this operation and the wobbler/D.T.I. set-up for accurate alignment.

When the profile is complete the corners can be rounded to a radius of about 1/32 inch.

If you intend to go to the extra trouble of making and fitting the dummy flanges, you will require a special tool to obtain the correct profile. The radius should be about 0.200in. as shown on the drawing. The flanges are not essential but they add a pleasing effect to the finished engine. They can be omitted if you are not bothered. I put them on my engine because I just happen to have a couple of small milling cutters previously purchased at an M.E. Exhibition. Obviously non-standard at 0.350in. dia. and 0.110in. wide, they were ideal for machining the two grooves into the sides of the front housing. The method I used for this should be fairly clear from the drawing. With the workpiece securely bolted to an angle plate mounted on the milling table and the set-up accurately aligned, the grooves may be milled by taking several small cuts to the depths shown on the drawing.

The flanges themselves are made from pieces of HE30 light alloy machined to 0.110in. thickness, filed to shape, fitted and secured with a touch of cyanoacrylate adhesive.

Machining of the housing is completed by positioning and boring the hole for the front camshaft bearing. My method for this job was first to set a piece of 7/32in. dia. silver steel to run dead true in the 4-jaw chuck (using a D.T.I.). turn a 60deg. point which I stoned to a dead sharp condition. The front bearing housing was fitted to the crankcase, aligned true with respect to the profile and clamped in this position using a tool maker's clamp or a 2BA threaded tie rod through the housing and case. The 7/32in. dia. silver steel punch was inserted point first into the rear camshaft bearing hole and pushed through to the front to make a centre mark on the rear face of the housing flange. This mark was then centred in the 4-jaw chuck in preparation for boring the camshaft bearing hole.

A simple jig is required to hold the housing without damage during this operation. I used a slice of 2in. dia. mild steel faced to lin. long and centre punched 0.60in. off-centre on one side to

locate a 2BA clearance hole drilled through the disc. The housing was bolted to this, front face to the fixture, with the carefully made camshaft bearing centre mark on the flange fairly well in line with the centre of the 2in. dia. fixture. Held in the 4-jaw chuck, the fixture was adjusted until the centre mark on the housing flange ran dead true (with the aid of a wobbler and D.T.I.) The hole was centre drilled, drilled and bored to 7/32in. dia. for a phosphor bronze bearing. This operation is shown in **photo 12**.

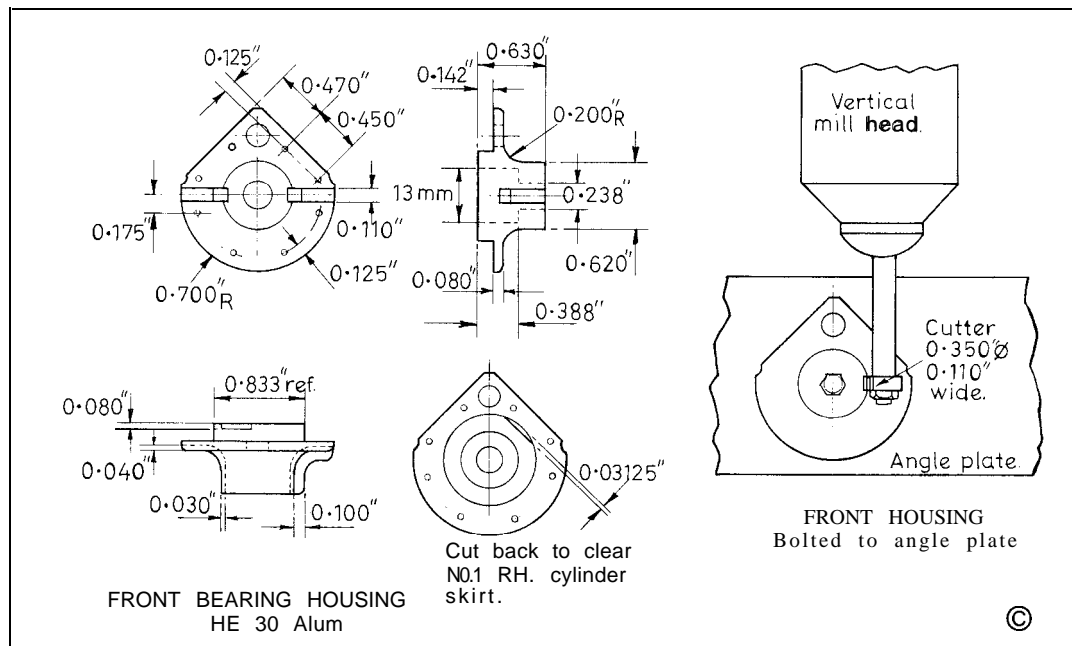
The eight holes for the 12BA fixing screws can now be carefully marked out on the front face of the housing. The top ones have been arranged to clear the four front cylinder head fixing screw holes in the cylinder mounting faces. The four bottom holes are not critical. All eight should be drilled No.55 for 12BA clearance. The corresponding tapped holes in the front face of the crankcase must be left until the front camshaft bearing has been made and fitted.

All sharp corners should now be removed with fine emery and the entire front bearing housing brought to the finish of a miniature casting.

Rear bearing housing

The rear bearing housing doubles as the timing gear case and since profiling of the gear case is best completed with the gear cover plate screwed in position, it is better to start by sawing or parting a thin section of HE30 light alloy for the cover. Set this piece to one side and saw or part off another piece 0.750in. long for the rear housing. Face this piece ready to mark out for boring the ball race seating. The shape of the rear housing means that it will be necessary to offset the workpiece in the 4-jaw chuck in order to centralise the crankshaft position, so mark the piece carefully, using the dimensions shown on the drawing and make a centre mark to enable the entire housing to fit within the 2in. diameter of the material.

Grip the material in the 4-jaw chuck and set the centre mark to run true. Centre drill, drill and bore for the single ball race and the rear crankshaft clearance hole, in much the same way as



The next phase of the work on the rear housing requires the use of a rotary table to achieve a neat appearance and to facilitate the work. I used a 4in. dia. rotary table previously made up from a kit of parts. The time and trouble it has saved have proved its worth many times. I can only guess at the problems to be overcome in making the housing without a rotary table, so if you can lay your hands on one for this job, so much the better.

At this point, the gearcase cover should be prepared for attachment to the case using the five holes shown on the drawing. If the plate is not machined with the case it will not be easy afterwards to get the two parts identical. The 2in. dia. piece cut earlier for the cover should be machined to about 0.050in. thickness. This is probably best done by milling but, whichever way you choose to

for the front bearing housing, except that this bore accommodates one ball race, not two. The 0.833in. dia. by 0.142in. register should again be turned before the work is disturbed, aiming for the same hand push fit into the crankcase as previously described. The sharp corner should be removed with a needle file. I may not have previously referred to 'breaking' sharp corners, but all corners which are neither chamfered or radiused should be broken with a needle file or fine emery even though no reference to this may have been made on any of the drawings.

At this stage the work may be removed from the chuck and the camshaft position marked on the housing flange as before. The workpiece should be fitted into the rear of the crankcase and carefully aligned to ensure that the entire profile of the gear case lies within the 2in. diameter of the material. Once clamped in place, the flange can be marked using the pointed silver steel punch, this time from the front of the crank case.

The 2in. dia. steel fixture can be used once more, this time to mount the workpiece for centering and boring the rear camshaft bearing position using the 4-jaw chuck. The centre mark is set to run dead true, centre drilled, drilled and bored to 0.250in. diameter before removal from the chuck.

Remove from the steel fixture and mount the work in the 3-jaw chuck, holding it by the 0.833in. register. Bore the recess for the smaller (18 tooth) crankshaft gear to 0.432in. dia. for a depth which leaves 0.100in. thickness of material between the ball race recess and the gear recess. Face the workpiece at the same setting to finish 0.338in. from the crankcase mating face.

The bore for the larger (36 tooth) gear can be machined with the work mounted on a mandrel using the 1/4in. dia. camshaft bearing hole. Turn the mandrel to a very shallow taper-when I do this, I usually set the compound slide over by just the thickness of the engraved line on the base of the slide. No more than this is necessary. Polish the mandrel with fine emery and push the workpiece onto the mandrel firmly enough to

withstand the force of cutting without slipping. The gear recess should be bored to 0.805in. dia. down to the same level as the smaller gear recess. Care must be exercised while boring since this larger bore will break into the previous smaller bore giving rise to an intermittent cut which may dislodge the workpiece. On completion of this stage, the workpiece can be removed from the mandrel.

The rest of the machining on the rear housing is mostly rotary table work, but first the outline of the crankcase must be marked onto the mating face of the housing flange as it was for the front housing. This is best done with the aid of a spigot made from a piece of mild steel about Min. long with half its length 7/32in. dia. and the other half 1/4in. diameter. The housing should be fitted into the rear of the crankcase and the two camshaft bearing holes aligned. The spigot is then inserted to accurately align the two components. The flange can be marked by scribing from the case profile.

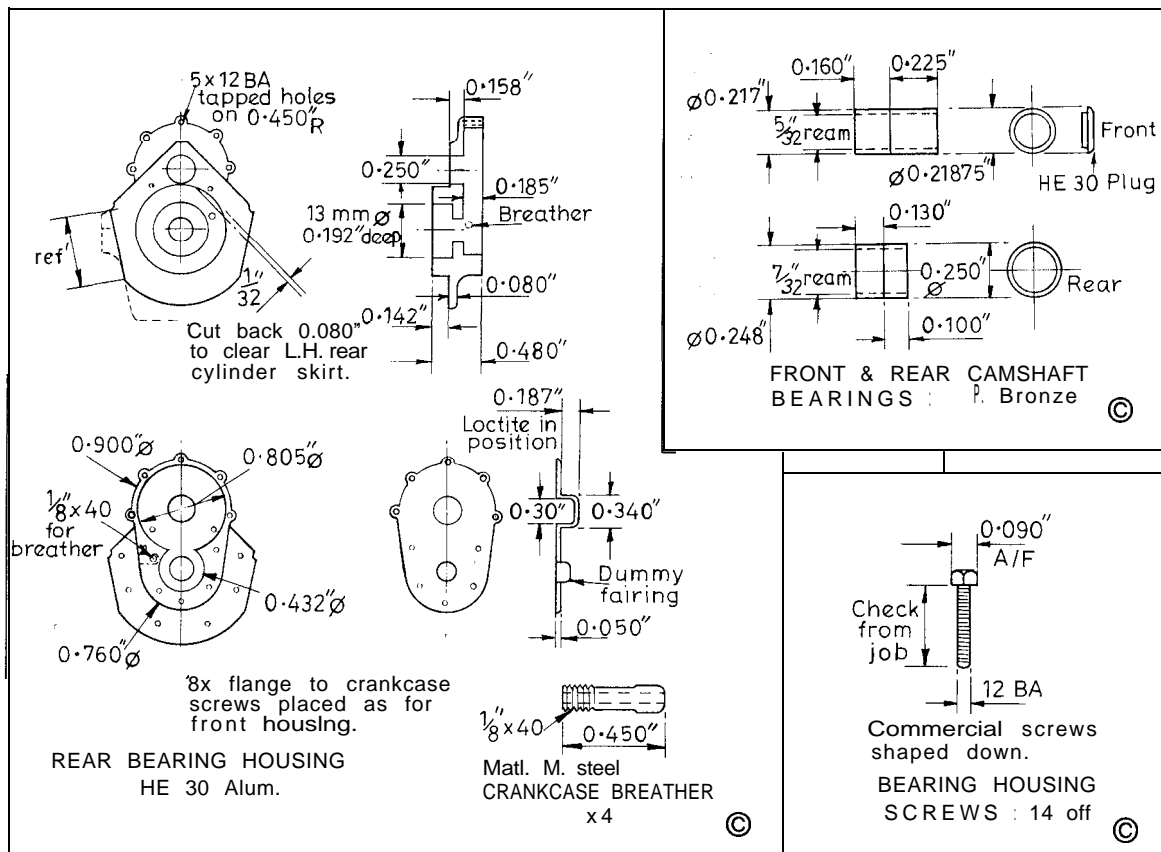
The top part of the gear case is now marked out on the flange face side and surplus material removed by sawing and filing to the scribed lines. If you prefer to finish by milling, saw and file close to the lines, clamp the work to the milling table, scribed lines up, with one of the top straight lines aligned with the table surface. Fit a 1/8in. ball nosed cutter and mill along the front of the upper gear case to the line with this cutter to a depth of about 0.100 inch. Turn the work through 90deg. and mill a groove along the other side. A plain cutter may then be used to bring the rest of the surface to the same level, taking particular care not to cut into the 1/16in. radii of the previously formed grooves. When the gear case is fitted to the crankcase the two radii should blend nicely into the two cylinder mounting faces. A little work with needle files (sometimes wrongly called Swiss files), scrapers and emery may be necessary to obtain the desired result. The five 12BA holes around the top of the gear case can then be marked out and drilled for tapping 12BA.

go about it, you should finish up with a flat piece large enough for the cover shape.

Prior to machining, the gear case shape must be marked out on the cover. For this, the centres of the two timing gears must be accurately positioned on the cover piece by using the same method as for boring the gear recesses, i.e. 3-jaw chuck for the small gear and spigot for the large gear. Mark with a 1/8in. centre drill at each position and remove from the lathe to mark out the gear case outline from these two centre marks. At the same time the bottom 12BA screw hole in the cover can be drilled and tapped to secure the small gear end of the cover for milling. Mark the five screw holes through the gearcase onto the cover piece, drill 12BA clearance and tap the holes in the case 12BA. Screw the cover to the case temporarily with five cheese head screws and remove the excess material from the plate by sawing or filing.

Since the shape of the cover consists of two half-round and two straight sections, I found it easiest first to machine the straight bits, then the smaller radius followed by the more complex larger top radius. With the case clamped to the milling table gear side up, and one of the straight sections aligned true, a 1/4in. dia. ball nosed cutter may be used to mill along the scribed line to a depth of 0.258in. on the case (or 0.308in. inclusive of the 0.050in. thick cover). Take the cut to the scribed line, align the other scribed line and repeat the cut. Fit an ordinary 1/4in. dia. cutter and remove the remainder of the unwanted material, being careful not to cut into the 1/8in. radius left by the previous cut.

Repeat these operations on the other side to leave the flange thickness at about 0.080 inch. The radius around the small gear part of the case can then be milled with the same 1/4in. dia. ball nosed cutter, having first made a mild steel spigot to fit both the rotary table centre and the crankshaft hole in the case. Fit the spigot to the rotary table and mount the case onto it, clamping with the 0.833in. dia. register hard down onto the table and being sure to keep the clamp clear of



tool for this job. Such a tool can be made from a piece of 1/8in. square silver steel with an 0.080in. dia. hole drilled through the width 1/8in. from the end. The end of the piece is then filed down until only one third of the diameter of the hole is left. The tool is then hardened and a slight front clearance ground in. Here now is a tool to shape the tops of the lugs to a radius of 0.040 inch.

To use the tool, make sure its small radius is sharp, mount it on its side in the tool post at centre height. mount the case on a spigot in the 3-jaw chuck using the camshaft bush for location. The spigot should be turned with a slight taper. Index by eye and take very light cuts—0.001in. is all that the set up will take. This is a slow job but the finished result is worth the

time and trouble taken. The alternative is to file and scrape each lug to shape.

the radius to be cut. The cut should be taken to the scribed line and to the same depth as the previous straight cuts. Strict adherence to the scribed lines is not too critical provided the radius blends smoothly with the straight sections. The regular milling cutter should be returned to the milling machine spindle and surplus material removed to the same level as the previous cuts.

Remove the work from the machine and make another spigot for the camshaft centre hole. Remount the case onto the new spigot to mill around the larger top radius of the gear case. Use a 3/32in. dia. cutter to produce neat looking lugs at the five screw hole positions. Take several small cuts up to the scribed line and within 1/32in. of the screw hole. Lift the cutter clear of the work while rotating to the next position. Try to get the screw holes in the middle of the lugs by using an eyeglass when approaching the lug with the cutter. If the cover has been attached with screws with suitable sized heads, the cutter can be taken to the point when it just grazes the OD of the heads. This is one way of getting the screw holes more or less in the middle of the lugs, important in a complicated piece of miniature engineering like our little VS.

The work can now be removed from the rotary table and remounted on the crankshaft centre spigot to rotary mill the lower flange area to 0.700in. at the same radius as the cut back radius of the lower crankcase. The sloping straight sections are filed to the scribed lines then the housing fitted to the crankcase and checked all around to ensure the profiles coincide. The case should now be cleaned up to remove all machining marks, and the corners smoothly radiused

around the flange. The eight 12BA clearance holes are marked out in the same positions as those on the front bearing housing and drilled 12BA tapping size.

Before the crankcase is drilled for the front and rear housing fixing screws, the two camshaft bushes should be made and fitted. Machined from 5/16in. dia. phosphor bronze rod, follow the drawing and these should need little explanation. Both bushes should be a press fit in the housings and an easy fit in the crankcase ends. The front one is reamed 5/32in. and the rear one 7/32in. before the rear housing can be fitted. The 7/32in. rear camshaft hole in the crank case must be bored out to 5/16in. dia. to receive the 0.248in. OD of the rear bush. This must be done with some precision or the bronze bush will either bind or not fit at all. One way to deal with this is to set the crankcase on an angle plate bolted to the face plate, in the same way that the camshaft bearing holes were bored initially. Insert the piece of 7/32in. dia. silver steel through the three camshaft holes, set the end of the silver steel to run dead true using the DTI, remove the silver steel and bore the hole to 1/4in. dia. through.

The rear housing can now be fitted to the crankcase and the eight fixing screw holes spotted onto to the end of the crankcase. Drill through with the 12BA tapping size drill. The flange holes are opened out to 12BA clearance and the crankcase holes tapped 12BA. Repeat for the front housing. The tops of the five 12BA screw hole position lugs on the upper part of the gearcase should be rounded off to complete the finished appearance of the case. This is rather more easily said than done. I went to the trouble of making a small half round concave shaping

time and trouble taken. The alternative is to file and scrape each lug to shape.

The front and rear housing fixings are standard 12BA hexagon headed screws reduced to 0.090in. AF. For this, I drilled a piece of 0.090in. diameter brass with a 12BA tapping drill to a depth of about 1/2in., then opened out 1/4in. deep to 12BA clearance and tapped the bottom portion 12BA. This brass holder was held in the 3-jaw chuck and a parting tool mounted on its side in the tool post. Each screw in turn was then screwed into the brass holder up to its head and tightened lightly against end of the brass. The head was then reduced by a shaping action using the sixty tooth bull wheel for indexing. I have put a touch of bright orange cellulose paint on the top of every tenth tooth of the bull wheel of my lathe to facilitate indexing. When the six faces have been reduced, the hexagon can be finished with a small 30deg. chamfer. Mild steel washers are also required for these screws. Make them 0.100in. OD and about 0.015in. thick and, before parting them from the bar stock, put a tiny 30deg. chamfer on each and polish at high speed with 1200 wet-or-dry paper.

The two top fixing screws for the rear housing are located in the large timing gear recess, and must therefore be countersunk to clear the timing gear. The gear case cover is secured with 12BA studs and 14BA nuts tapped out to 12BA. The five 12BA holes around the case top should be tapped through and fitted with 12BA steel studs of suitable length and held in place with cyanoacrylate adhesive. If you can't obtain 14BA steel nuts these can be made as previously described but to 0.070in. across flats.

● To be continued.

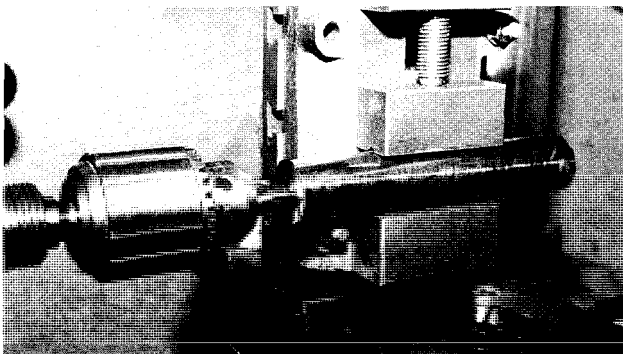


Eric Whittle

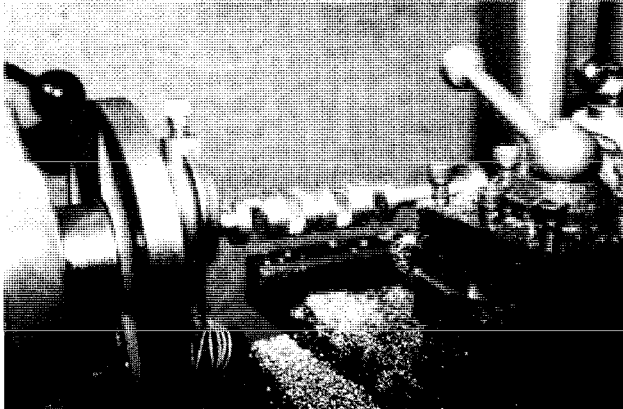
continues the description of his 10.6cc aero engine with details of the cam follower guides and advice on the manufacture of the crankshaft.

● *Pari III continued from page 610 (19 May 1995)*

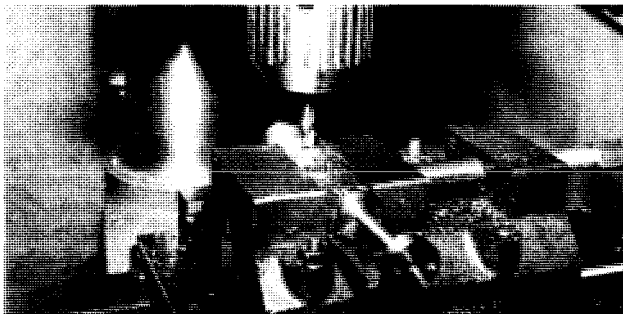
Fourstroke Aero Engine



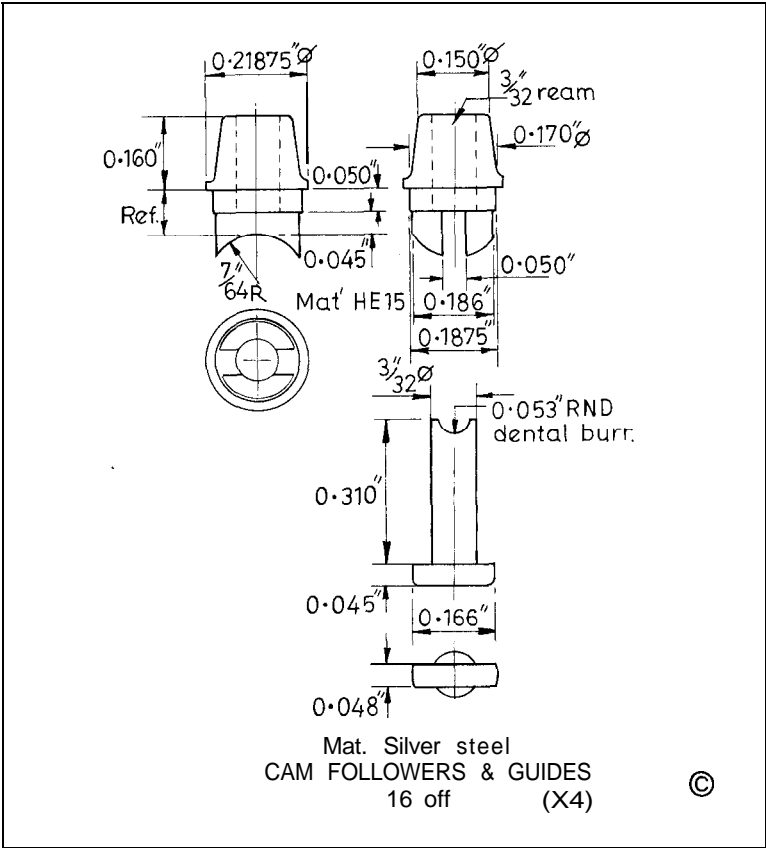
13: A 6in. faced length of lin. dia. EN16T is mounted in a machine vice on the vertical slide and aligned with the aid of a dti before a 1/4in. centre drill is used to drill three centre holes on which the crankshaft will be turned.



14: The workpiece is set in turn on the crank pair centres to machine the journals pair by pair by taking small cuts having previously ensured that the tool is correctly positioned before starting the lathe.



15: When the three main journals and four crank pins are within about 0.010in. of their finished diameter, the crankshaft webs are milled to their final width with the crankshaft alignment set with respect to the opposite crank pin pairs using a depth gauge.



Cam follower guides.

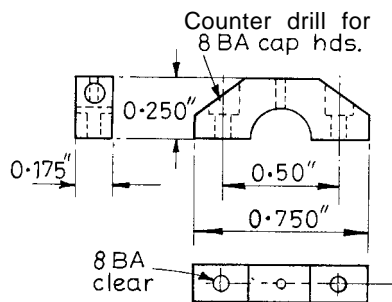
The basic crankcase construction is completed by the cam follower guides. These are made from HE15 aluminium alloy which has good wearing qualities and is a pleasure to machine. Owing to the limited thickness of material-only about 0.110in.-above the camshaft gallery, the height dimensions are a little critical. Study of the drawing will reveal the guides to be slotted at their bottom ends; this is to prevent the cam followers from rotating in operation and fouling adjacent cams. No trouble should be experienced if specified dimensions are followed fairly closely; study of the drawing will reveal that arrangements have been made to provide some 0.010in. of further movement to the cam followers at their maximum height. This ensures free operation of the followers in the guide slots. The diameter of the slotted part is reduced by a couple of thou to prevent any

tendency to slight closing up of the slots when the guide is pressed home into the crankcase.

To machine the guides start by holding a 3/4in. length of 7/32in. dia. HE15 aluminium alloy in a collet and turn to 3/16in. dia. for 0.160in. length. Then reduce this diameter to 0.186in. for 0.110in. leaving 0.050in. of the 3/16in. diameter. Now centre drill, drill and ream 3/32in. right through the workpiece and remove it from the lathe.

To mill and slot the work, mount it at dead centre height in the tool post and set the 3/32 in. bore at 90deg. to the lathe bed. Fit a 7/32in. dia. milling cutter in the spindle nose collet and carefully machine the 7/64in. radius into the end of the workpiece until the curve is 0.095in. from the upper flanged part of the guide. Now fit a 0.050in. wide slitting saw to the lathe spindle and cut the slot up to but not into the 0.050in. length of 3/16in. diameter.

Remove the work from the lathe and hold it on the 3/16in. dia. in a collet to form the upper part of the guide. Light cuts are necessary here as the 3/16in. dia. by which it is being held is only 0.050in. long. Use a sharp tool with the tip stoned to a tiny radius and turn the little base flange about 0.025in. deep. The guides should be pressed into the crankcase with Loctite 601 or whichever other cyanoacrylate structural adhesive you prefer, but remember to check the alignment of the slots before pressing them home.

CENTRE MAIN CAP
HE 30

©

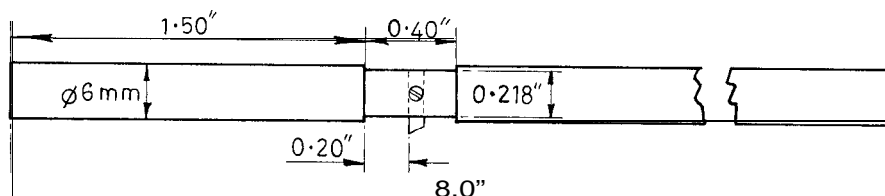
This isn't super critical but you should make the effort to get it to look right.

The cam followers are made from silver steel and hardened right out without tempering. Start with a length of 3/16in. dia. silver steel and turn a 0.310in. length to 0.0945in. dia., then turn a further 1/16in. to 0.166in. dia., polish the 3/32in. dia. shank with 800 wet or dry paper until a good sliding fit is obtained in the follower guide. I find it best to back the abrasive paper with a 6in. steel rule and use it in the manner of a file. The half round seat for the lower end of the push rod is made with a 0.053in. dia. dental burr (surplus to requirements from my friendly local dentist). Feed the burr in for a depth of 0.050in. then part the piece off to leave the 0.166in. dia. 1/16in. thick.

Make 16 followers to this stage.

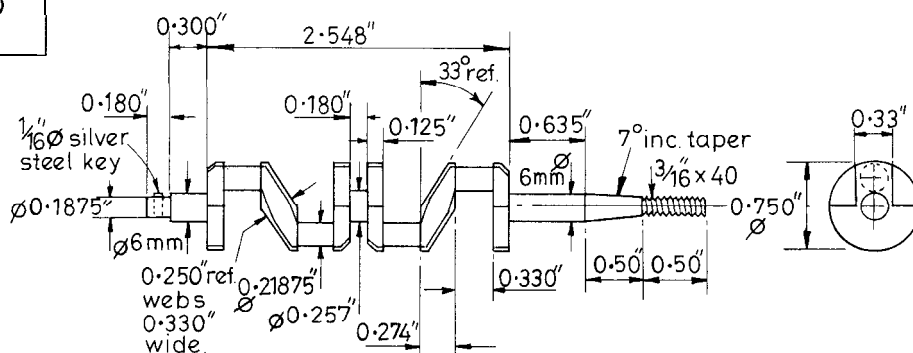
Now face each follower head to finish at 0.045in. thickness and put a small radius on what will be the lower corner of the 0.166in. dia., as shown on the drawing. Reducing the head to 0.048in. to fit the guide slots will require a simple fixture to hold the follower in the toolpost so that the unwanted bits of the head can be removed.

A 2in. length of 3/8in. square mild steel bar should be centred in the 4-jaw chuck, faced and centre drilled, then drilled and reamed 3/32in. by 3/4in. deep. Using a 0.050in. slitting saw, the fixture is then slit down the middle for the depth of the reamed hole to make a 2-jaw collet in which the followers can be held. This is done by clamping it in the four way tool post aligned at 90deg. to the lathe bed or spindle so that the two jaws close onto the follower shank. 0.060in. is to be removed from each side of the 0.166in. dia. head, so if the head is touched onto the face of the saw, the work withdrawn from the saw and moved to the left for 0.060in., the surplus metal can be removed from that side of the head. The work is then moved to the other side of the saw and another cut taken. The depth of the cuts should be at least 0.045in. but no more than 0.050 inch. Fitting the followers into the guides will necessitate the follower being inserted



CENTRE MAIN BEARING LINE BORING BAR : Silver steel

©



CRANKSHAFT EN 16T steel

©

90deg. out of line-i.e. with the head of the follower in line with the crankcase. When the follower head is inside the camshaft gallery it can be turned and inserted in the guide slot, a pair of tweezers is the tool to use here. Any excessively tight fits can probably be cured (or made acceptable) by rotating the follower through 180deg. Before final fitting, each follower should be hardened out and the 3/32n. shank polished with 800 wet or dry paper.

Centre main bearing cap

The centre main bearing cap is the last part required to complete the crankcase assembly. Make it from HE30 alloy and use 8BA cap head screws to secure it to the crankcase centre web. Line boring can be left until the crankshaft has been made but we can usefully drill the bearing position in readiness for the final boring operation.

With the two halves of the crankcase screwed together and mounted on the face plate and angle plate as they were for boring the case ends, then aligned dead true lengthwise and the 0.833in. dia. bore set true using the dti, the bearing cap and centre web can be centre drilled and drilled 0.240in. diameter. The cap must be marked to identify which way round it is fitted to the centre web. Using a 1/32in. dia. drill, the cap and web can then be drilled for the oil passageway as shown on the crankcase drawing.

Line boring tool

The line boring tool can be made up at this stage. I used a piece of 6mm dia. silver steel. The cutting bit was ground from a broken &in. drill

and secured in place by means of a 10BA grub screw. I found it an advantage to case harden the grub screw.

Crankshaft.

In conjunction with the bronze bearing shells fitted to the con-rods, I have found unhardened EN16T steel to be a satisfactory material for the crankshaft. Start with a 6in. length of lin. dia. EN16T and face both ends. Mount the piece in the machine vice on the vertical slide (**photo 13**) and check the horizontal alignment with a dti. Check also that it is truly aligned with the lathe bed. Fit a 1/4in. centre drill in the collet and move the work up to the centre drill to position the drill tip at the centre of the faced off workpiece. Using the cross slide index dial, now move the work forward 0.250 inch. Remove the freeplay from the feed screw and set the index dial to zero. Drill a full centre. Move the workpiece back by 0.250in. to drill a second centre, then a further 0.250in. to drill a third centre. Pay attention to and eliminate backlash at all times to maintain the necessary accuracy.

Turn the vertical slide through 180deg. and repeat the foregoing on the other end of the workpiece. With the workpiece mounted between centres in the lathe, the outside diameter can be reduced and finish turned to 0.750in. before spacing out the three main journals and the four crank pins. For this, grind a parting tool to about 0.080in. wide and set it in the tool post.

The various journals and web positions must now be spaced out along the crankshaft blank. Everything can be positioned relative to front face

It is now time to have a go at turning or facing the inclined surfaces of the two intermediate webs to an angle of about 33 degrees. Check this angle as the job progresses. The faces must be machined using the opposite crank pin centres—i.e. the centres furthest from the face being machined. As with the journals, take light cuts on the inclined faces, machining little by little and keeping both sides of each web even.

The crankshaft is completed with the 18T gear key. This requires a 1/16in. dia. hole to be drilled through the gear seat and a piece of 1/16in. dia. silver steel secured in place with your favourite cyanoacrylate adhesive. To align the hole accurately with the vertical axis of the crank throw, the shaft should be returned to the machine vice in the manner that it was held for milling the webs, except that this time it should be held with the crank throw vertical and clamped across one of the two inclined webs using two pieces of 3/8in. square steel between the vice jaws and the crank webs. The three main journals should, of course, be set horizontal. Put a 1/16in. cutter into the milling spindle, position the cutter in the middle of the gear seat and just touch the top of the seat with the cutter. Lower the cutter by 0.002in. and move the work sideways either side of the cutter-this will produce a tiny rectangu-

lar flat dead in line with the crank throw. Mark the middle of the flat with a scribe point and centre it under the milling spindle before drilling the 1/16in. dia. hole through the shaft. When fitted, the key must be reduced in height to just enable the ball race to be installed on its seating.

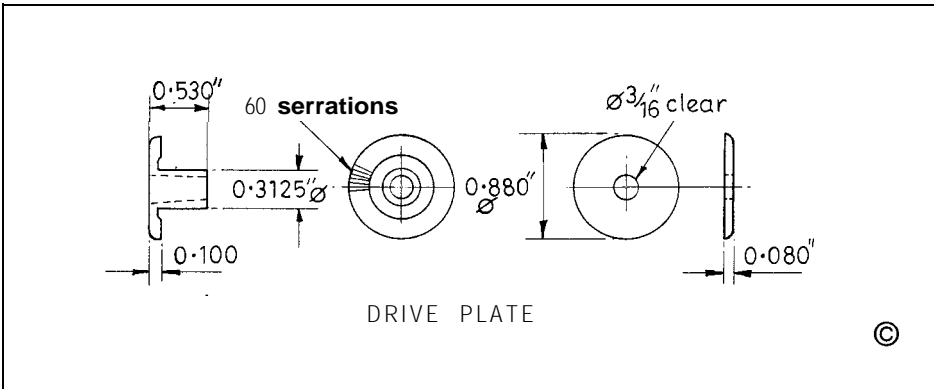
Line boring

The boring has been completed between the front and rear ball races and should therefore be exactly concentric with the crankshaft main journals. Check the bearing diameter with a plug gauge and reduce and polish the centre main crankshaft journal to 0.003in. undersize, fit the shaft into the case with all components and screws, etc. in place and check for freedom of rotation. There should be 0.005-0.010in. of end play in the shaft.

Drive plate and washer

The drive plate and washer require little explanation. Make them from EN8 steel or at least something a little tougher than mild steel. Cut the 60 serrations with a tool ground to 45deg. and mounted on its side in the tool post. Use the cross slide to move the tool.

**To be continued.*





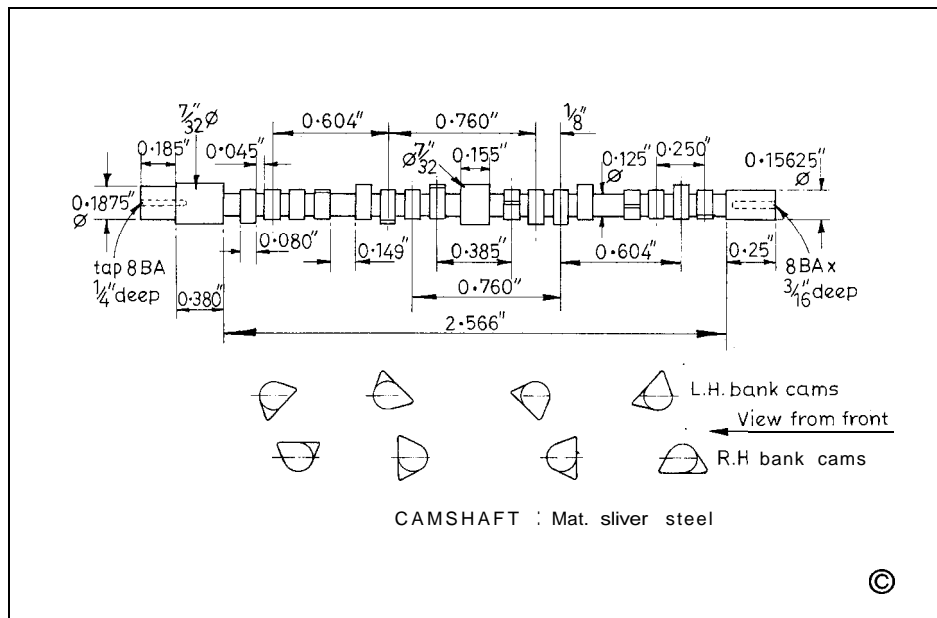
16: The one piece silver steel camshaft is hardened and tempered after manufacture. Shown here during machining, the 16 cams are milled in a special indexing fixture.

Camshaft and timing gears.

The camshaft is a one piece component in hardened and tempered silver steel. The 16 cams are cut by end milling in the special indexing fixture shown in the drawing and in **photo 16**, the cams are cut to give a firing order of 1, 4, 3, 8, 7, 6, 5, 2. There are of course other firing orders suitable for a V8 but the one chosen certainly gives smooth and satisfactory running.

It will be noticed that cam flanks and followers both have flat or straight working faces. This is generally considered to be bad practice, but in the scale we are dealing with (about 1/10 any adverse effects are much reduced and do not outweigh the advantage of ease of manufacture. The three journals are sufficiently large to cope with the working stresses.

We must first turn the shaft with its sixteen cam blanks and three journals to the dimensions shown on the drawing. This is done in much the same way that the crankshaft was spaced out. A 4-1/2in. length of 1/4in. silver steel is chucked in the 3-jaw, faced off and centre drilled one end. Then, with 4in. protruding from the chuck and supported with the back centre, the work is reduced to 0.220in. dia. to a fine finish. A parting tool should next be ground to 0.045in. width and set in the tool post. Touch the front face of the work piece with the left hand edge of the tool and make a note of the lead screw reading. Now move the tool to the left by 0.320in. and take a 1/32in. deep cut to establish the front face of No.1 cam. Withdraw the tool and move a further 0.125in. to position the rear face of No.1 cam



and the front of No.2 with another 1/32in. deep cut. The drawing shows all the necessary dimensions to determine tool movements for the correct spacing of all 16 cams and 3 journals.

When the positions of all cams and journals have been determined by 1/32in. deep cuts, the spaces can be reduced to 0.150in. dia. and all 16 cam blanks to 0.200in. dia. with a fine finish. The front journal should be turned and polished to 5/32in. dia., the centre and rear journals to 7/32in. diameter. All the space diameters should be further reduced to 0.125in., which is about 0.007in. less than the cam base diameter. Using a right hand knife tool, the 3/16in. dia. gear seat is machined at the same setting-although it **could** be machined afterwards having set it to run dead true in the 4-jaw chuck. Otherwise, make sure **all** necessary work is done before removal from the chuck.

The rear end of the shaft should be faced to length and drilled and tapped 8BA. for 3/8 inch. Check for freedom of rotation in the crankcase bearings.

The 36 tooth gear is already finished to 3/16in. bore as received, so the gear seat should be made a hand push fit into the gear boss. The 5/32in. dia. front journal should also be drilled and tapped 8BA as it will be necessary to secure the shaft against end movement due to the cutting forces when the cams are being milled in the fixture.

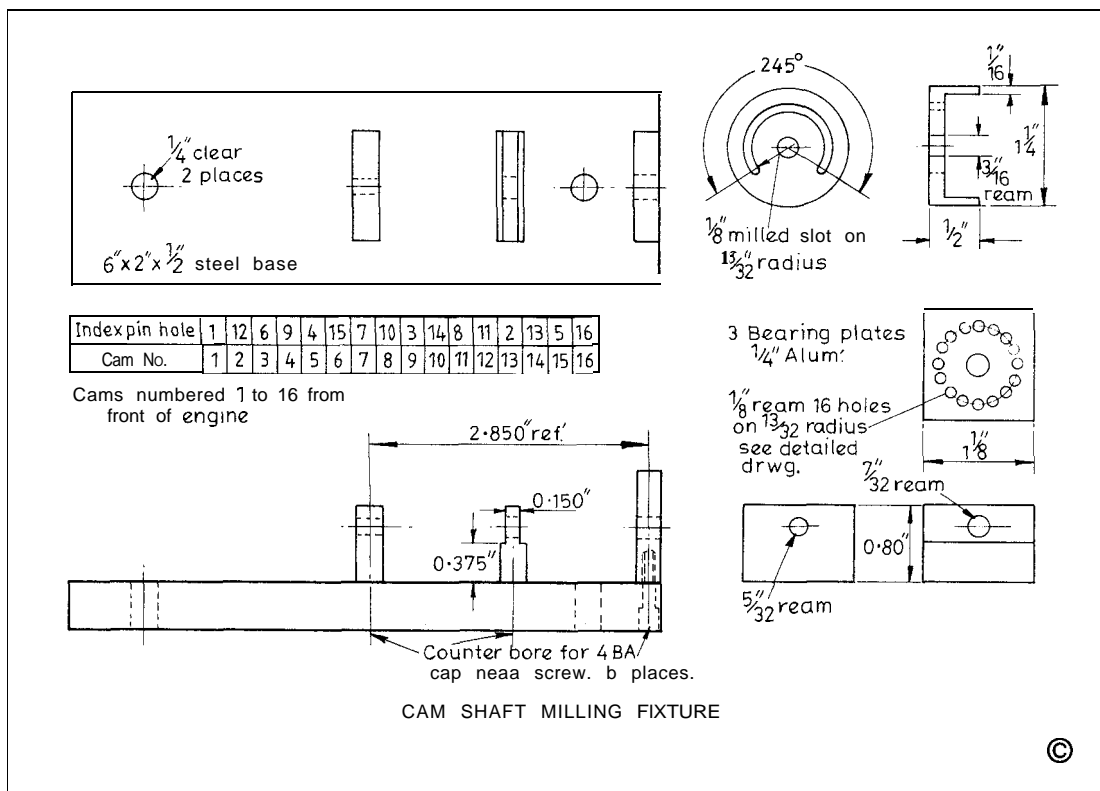
Camshaft milling fixture

Before any further progress can be made, the camshaft milling fixture must be prepared. A fairly simple device, this is made from three pieces of 1/4in. aluminium alloy plate and a piece of 1/2 x 2 x 6in. mild steel. The fixture is a straightforward job but requires care in the manufacture of the three plates since it is important that the cam shaft is held truly parallel to the steel base. The plates are first cut out, drilled and reamed, one to 5/32in. and two to 7/32 inch. A short spigot is then turned with 7/32in. of 5/32in. dia. and 15/32in. of 7/32in. diameter. The three plates can then be mounted on the spigot and clamped in the machine vice under the milling head and one side of the sandwich of three pieces milled true. When separated, these three faces will be the base faces and will hold the camshaft parallel to the base when mounted on the steel base plate.

The plates are positioned along the base plate to the same dimensions as the camshaft bearings. When the plates are secured in place with the six 4BA cap head screws the camshaft should be free to rotate by hand. If the shaft is tight in the plate **do not** reduce the shaft since this has already been made to fit the camshaft bearings. Instead, make a couple of split brass laps like the one shown on the drawing for the con-rods and lap the offending bores with metal polish.

The front or largest of the three plates is the indexing plate and requires to be drilled and reamed for the 16 indexing holes at the alternate 20 and 25deg. angular positions shown. This work can be done on the rotary table at the same setting as when the annular slot is milled in the indexing wheel.

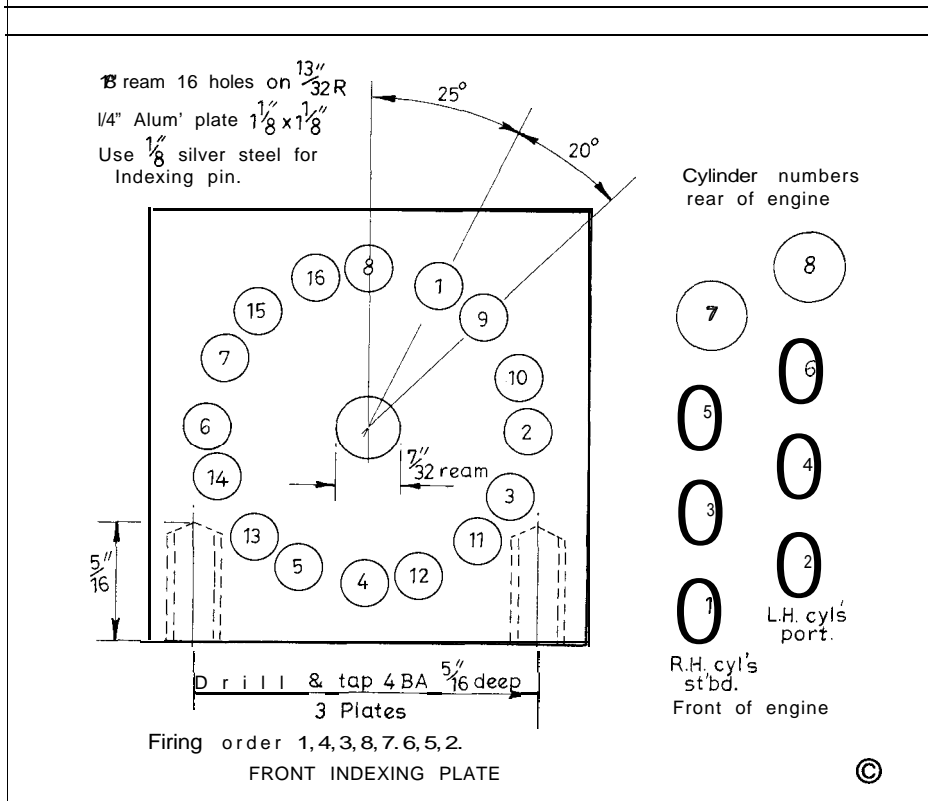
Start by making the indexing wheel as shown on the drawing. Then make two spigots, one 3/16in. dia. to mount the indexing wheel to the rotary table and the other 7/32in. dia. for the



indexing pin, check that the indexing wheel can be turned the full 245deg. from one end of the slot to the other. A little judicious work with a small scraper or needle file may be required and when everything seems satisfactory we are in business for machining the cams.

Machining the cams

Since the indexing holes are not numbered, to prevent confusion a centre punch mark can be made on the top edge of the plate in line with hole No.8. Indexing can then be done by counting from No.8, using the drawing to locate the correct pin hole. The fixture may now be bolted to the table of your vertical mill or, as in my case, the lathe boring table. I aligned mine with the lathe bed-indexing wheel towards the tailstock. Put the indexing pin into hole No.1 and fit a 1/8in. cutter in the milling head. Lower the cutter to just touch the top of No.1 cam blank.



Since nearly all end mills are ground with a little clearance on the ends of the flutes, positioning the cutter in line with the shaft to cut the cams is likely to produce slightly barrel shaped cam sections. This will not matter over-much since our cams are only 0.080in. wide and the effect will hardly be noticed. A simple way to overcome this is to displace the cutter to one side of the shaft centre line by about 0.030 inch. The cutter end flute clearance will then have less effect since most of the cutting will be done by the outer edges of the flutes. The cross slide index dial should be set to zero at this offset point.

Now we can have a go at cutting the first cam, turn the indexing wheel to the end of the annular slot and steady the wheel by hand while applying a 0.005in. cut. Slowly turn the wheel to the other end of the slot then, using cross slide movement, move the cutter along what will be the flank of the cam. Return the cross slide to the zero position, lower the cutter another 0.005in. and turn to the other end of the slot. Once again machine along the flank with cross slide movement, always returning to zero for the next cut.

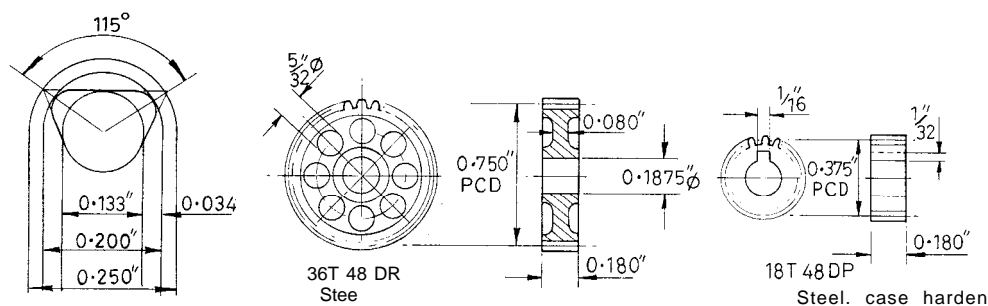
Continue like this until the base circle is reduced to 0.133in. dia. then reset the milling head feed dial to zero. You may think that the 0.005in. cut sounds a bit small, but you'll probably find it about right, anything much more than this may cause problems by distorting the work-piece, overstraining the fixture or causing chatter.

The indexing pin can now be inserted in hole No. 12 for cutting No. 2 cam. The cuts should be taken down to the zero on the milling head feed dial at which point the base circle diameter should be 0.133 inch. Keep a close check on the diameter as the cuts progress. Try to end up with identical base circle diameters. You may find the flank of the cutter breaks slightly into the two

indexing plate. Now clamp the plate to the table on the spigot, fit a t/sin. centre drill to the milling head and centre drill the 16 indexing hole positions. Then drill and ream each position 1/8 inch. Without moving the position of the milling head remove the plate and clamp the indexing wheel to the rotary table. Machine the 245deg. annular

slot in the wheel using a 1/8in. cutter.

Now fit the whole bag of tricks, complete with the camshaft, to the steel base plate, secure the indexing wheel to the shaft with an 8BA screw and washer, secure the shaft against end float with another screw and washer in the front journal and, using a piece of 1/8in. silver steel as an



in the camshaft. A two thou skim off the rear face of the gear and the same off the outer rim of the front face to give clearance to the rear face of the gear recess will most likely cure any problems. The 36 tooth gear is secured to the camshaft with an 8BA cap head screw and washer. This requires a small fairing to be

shortened aluminium plates due to the closeness of the adjacent cam blanks.

By the time you have cut these first two cams you'll have figured out how it all works. All you have to do to cut all 16 cams in the right places is follow the table with the camshaft drawing. When all the cams have been cut the shaft can be removed from the fixture and the tops or lobes rounded off with needle files. This is a tedious job and requires some patience-something you'll know all about by now! Be careful that you don't reduce the height of the cam lobes during the rounding off process because you'll reduce the cam lift if you do!

Timing gears

The large timing gear can now be machined to the dimensions shown on the drawing. The 0.080in. deep relief cuts should be cut in first, then the gear can be set up on the rotary table and the 8 x 5/32in. dia. holes centre drilled through and end milled in.

After having been bored to 3/16in. dia. for a nice snug fit on the crankshaft, the 18 tooth crankshaft gear must have a 1/16in. key way cut in it. I always go to the trouble of making a concentric tight fitting holder for this sort of job. Chuck a piece of 1/2in. dia. mild steel, centre and drill 1/4in. dia. x 3/8in. deep then bore for a depth of 0.200in. to a tightish fit on the O/D of the gear. Push the gear into the recess, make sure that it is truly and firmly seated, then bore out the 1/16in. dia. hole to a nice hand push fit on the 3/16in. dia. crankshaft seat.

Do not remove the gear from the fixture until the keyway has been cut. Grind a parting tool to 1/16in. width. Most of its depth must be ground away to enable it to be inserted through the gear boss. Set the tool at dead centre height on its side

in the toolpost and make sure that it can be inserted right through the boss without fouling. With the aid of an eye glass, position the gear so that the keyway will be in line with a gear tooth as shown on the drawing. Using saddle movement like those of a shaping machine ram, take the keyway to a depth of 1/32 inch. Keep the cuts small and go right through the gear boss-the previously drilled 1/4in. dia. hole will give the tip of the tool somewhere to go. Remove the gear from the fixture by turning the fixture almost down to the O/D of the gear and breaking the gear away.

Assembly

Assemble the crankshaft into to the crank case together with the camshaft and gears and check the mesh of the gears. The two shafts can also be checked for end float-there should be a little. Camshaft end float is controlled by the gear cover plate. Although the 18 tooth timing gear is held in position with a push fit on its keyed gear seat, the cover plate ensures that it cannot move very far anyway.

To fit the cam followers, first remove the crankshaft and camshaft and insert all 16 followers into their slots. Press them down to the bottom of the slots with tweezers while holding the crankcase in the inverted position. It is a good idea to fit the followers using a dab of thick oil (similar to steam cylinder oil) which should hold them in place should the crankcase be inadvertently turned the right way up before the camshaft is installed. Insert the camshaft, complete with its 36 tooth gear, into its bearings, fit the crankshaft and the 18 tooth gear, then fit the gear cover into place with all 10 screws.

Some minor adjustments will probably be necessary to obtain the right amount of end float

made and fitted to accommodate the screw head as shown in the drawing. The fairing is made a light push fit into the gear cover and is secured with cyanoacrylate adhesive. The smaller fairing for the end of the crankshaft is a dummy item and, if you're not bothered, needn't be fitted.

Final fixing of the 36 tooth gear involves the use of a cyanoacrylate retaining compound and must be left until we come to the timing of the engine after the cylinders, con-rods and pistons have been made and fitted.

Heat treatment

Hardening and tempering of the camshaft was left until the engine was completed and run for half an hour or so to help smooth the cam profiles, particularly the lobes. Whether there was any advantage in this is difficult to say for sure.

The camshafts of my two *Cirrus* engines were left unhardened. The cams are much wider than those of the V8, and the contact area of the followers much greater so the wear was virtually non existent and I considered hardening to be unnecessary. In the event, due to the narrower width of the V8 cams and despite the risk of distortion, I decided to harden and temper and, to my surprise the shaft did not distort at all.

The shaft was brought to red heat with the propane torch and plunged vertically into a quart sized plastic container of cold water. The three journals were polished with fine emery to steel brightness and the shaft tried in the bearings. It was a perfect fit and rotated with no binding at all. Tempering was accomplished with very low heat, playing a gentle flame from end to end until the three journals turned a light straw colour. The shaft was then plunged into cold water.

The 18 tooth crankshaft gear is case hardened.

● To be continued

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V8

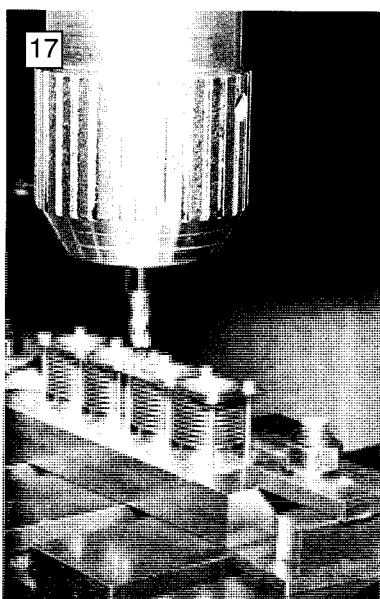
Fourstroke Aero Engine

Eric Whittle

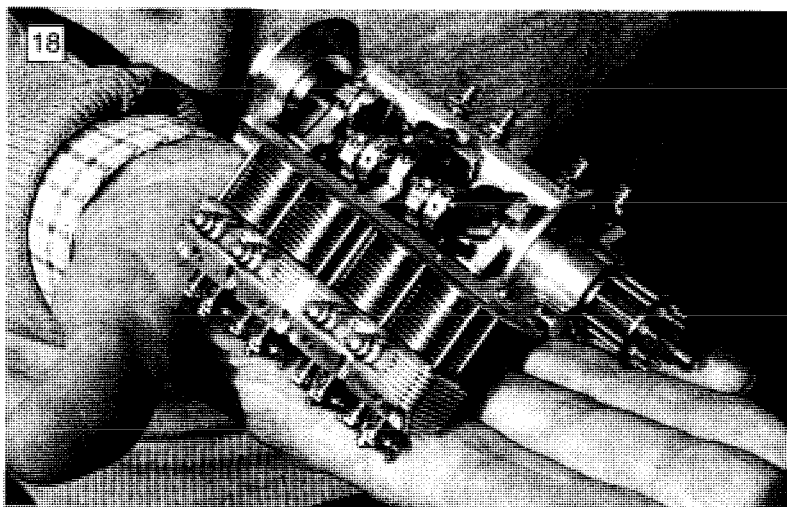
deals with machining the cylinders and describes how to make and use a cast iron lap to obtain a superfine finish.

● Part V continued from page 84 (21 July 1995)

17: The cylinders are held securely on a fixture while they are being machined to height under the milling machine head. A sharp cutter, small cuts and careful work are the order of the day for this delicate operation.



18: Partly dismantled and nestling in the builders palm, this view of Eric Whittle's V8 reveals a number of details including one of the banks of cylinders, the subject of this article.



Non-standard spanners.

Open ended and box type spanners to fit the 0.090in. and 0.070in. AF hexagons used on the crankcase can easily be made using mild steel for the box spanners and 1/16in. gauge plate for the open ended variety.

To make the box spanners, first make a broach. Turn a piece of silver steel to 0.010in. larger than the across-corners dimension of the hexagon head for about 1/2in. long, then mount a parting type tool in the tool post on its side and, using the bull wheel as previously described, shape the piece down to 0.002in. above the across-flats dimension.

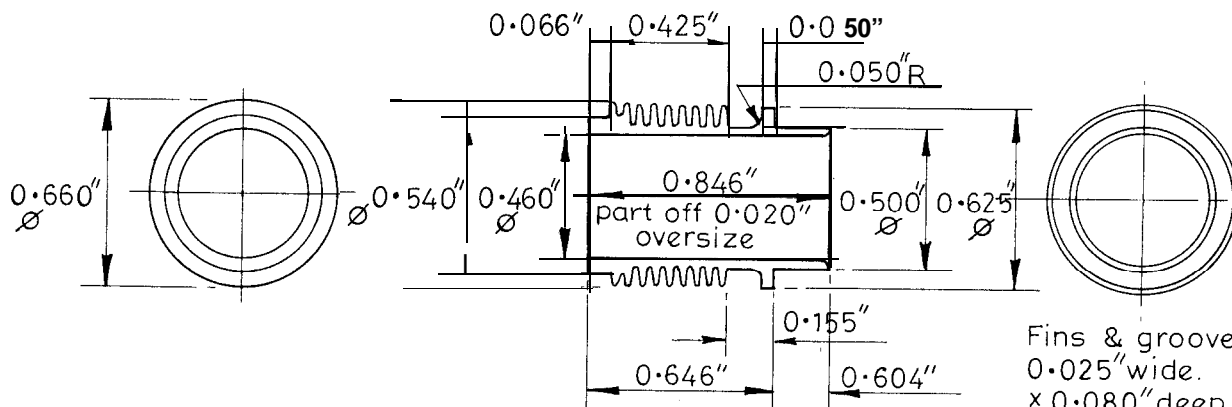
When this is done, introduce some rake to the cutting edges by drilling into the end of the workpiece with the point of a 1/8in. drill, clean up the burrs and harden out by quenching in water.

Now chuck a piece 1/4in. dia. mild steel and turn a 3/4in. length to 0.020in. over the across-corners dimension and

drill a suitably sized hole in the end for a depth of 1/4 inch. The hole size should be about 0.010in. above the across-flats dimension and should be countersunk with a centre drill to assist in centring the hexagon broach.

Put the broach into the tailstock chuck and, using some cutting oil, push it into the end of the workpiece to a depth of about 1/8 inch. Clean up the end and you have a perfectly good box spanner.

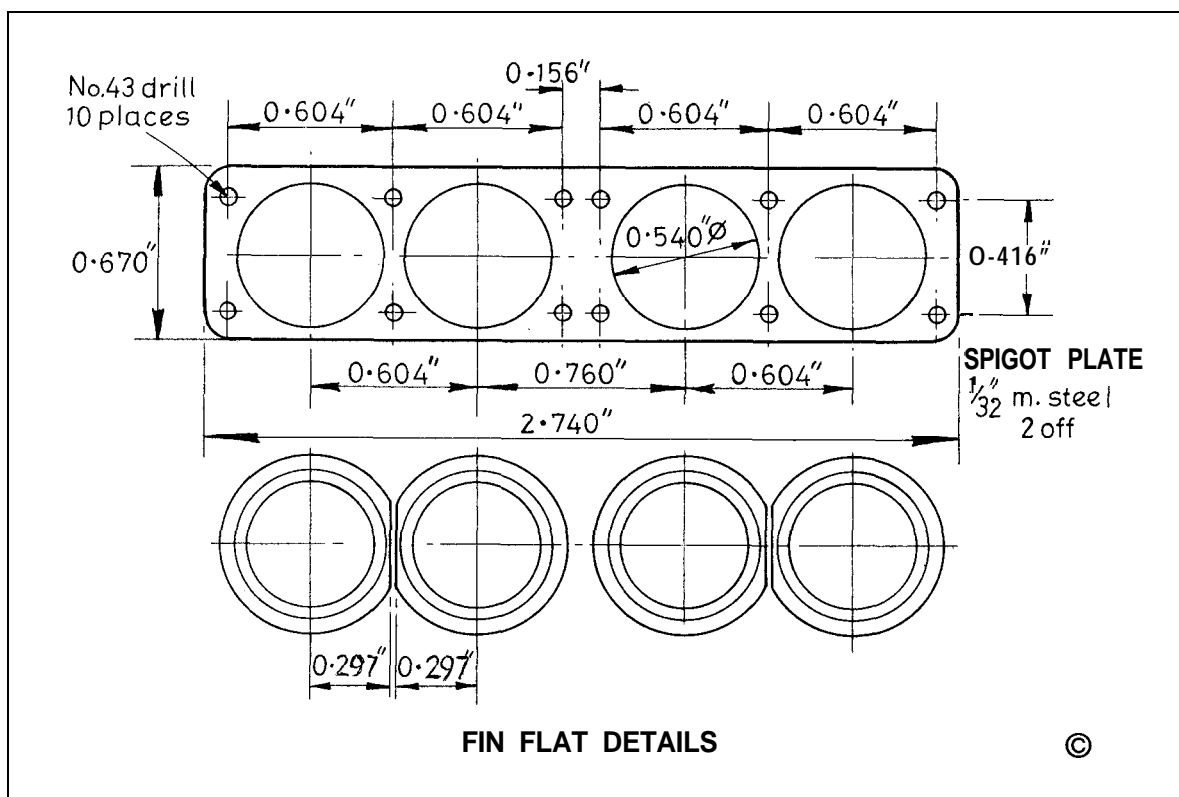
Open ended spanners are easier to make. Hold a suitably sized piece of 1/16in. thick gauge plate in the four-way tool post and form the jaws of the spanner with a 0.050in. wide slitting saw, move the saw a further 0.020in. for the 0.070in. A.F. screw heads and 0.040in. for the 0.090in. heads. The spanners can then be cut and shaped to form any desired angle for the jaws. Hardening is unnecessary since the tightening forces required for 12 and 14BA screws are so small.



CYLINDERS EN16T: 8off

Fins & grooves
0.025" wide.
x 0.080" deep.
Top groove 0.040" dp.
9 Sins.- 8 grooves.

©



Cylinders and spigot plates

The cylinders are made from EN16T steel which I have found to be better wearing than the EN8 **used** for the cylinders of some of my previous engines, although the hardened silver steel liners fitted to my first 5.3cc D.H. Cirrus are probably superior to the EN16T cylinders. The problems with making and fitting them are considerable since the liners distort during hardening and a great deal of time has to be spent on lapping the outside of the liner to fit the mild steel cylinder barrel before any start can be made on lapping the bore.

My second Cirrus is fitted with EN16T cylinders and to date has clocked some seven or eight hours running without any sign of wear or power loss, so I decided that EN16T would be good enough for the V8.

When listing the material requirements, I stated that 18in. of EN16T would be needed. We have already used about 5in. to make the crankshaft, this will leave about 12in. for the eight cylinders. The amount used will depend on the method of manufacture and your machinery, so 2ft. may be a better estimate than 18 inches. Some cutting oil or suds is also recommended to assist the operations and cool things down a bit.

When compared with what we have been doing so far, making the cylinders is a piece of cake. But this is only true provided we are careful and don't get impatient over the number of cylinders involved.

If you have a lathe which will take the lin. dia. steel through the headstock spindle, all well and good, but if not the bar will have to be either sawn or parted into manageable lengths. (lin. was the smallest diameter which I could obtain from my local stockist.)

Cooling fins

Start by chucking the piece with 1.5in. protruding from the jaws and turn to 0.66in. for 1.25in., then turn to 0.5in. dia. for 0.200in. to form the face of the mounting flange. Now grind a tool suitable for both left and right hand turning with a 0.050in. radius on the right hand corner and a 0.015in. radius on the left hand corner. Use this tool to turn to 0.625in. dia. for a further 0.155in. to position the smaller radius on the bottom face of the bottom fin. Note the lead screw index reading and turn between the fin and mounting flange to 0.5in. dia. leaving a flange thickness of 0.050in..

The steel we are using is tough requiring the use of a very carefully ground grooving or parting type tool to form the fin grooves without oversteering and breaking the tool. I used a ready ground parting tool blade 5/8in. deep and 3/32in. wide. This blade was ground with a shallow taper on each side to form the fins. Avoid too much side clearance which if excessive would reduce the depth of the tool. Full tool depth is needed to maintain adequate strength. The grooves are just 0.080in. deep and the tool is only an average of 0.025in. wide but EN16T is tough steel. Stone the front tip of the tool to a half round profile. Provided the tool is full depth you would have to be very unlucky to break it - I am, of course, talking about ordinary H.S.S. tool steel.

Set the tool in the tool post and then set the compound slide parallel to the lathe bed since it will be easier to space the fins with the index on the topslide rather than the leadscrew and saddle. Touch the middle of the half round tool tip exactly on the corner of the 0.625in. dia. of the bottom fin and move the tool

to the left for 0.0375 inch. This will position the tool correctly for the first fin groove. Set the slide dial to zero and, using the slowest ungeared speed and plenty of cutting oil, feed the form tool into the work for a depth of 0.083 inch. You will soon discover how fast or slowly to feed the tool by the sound and feel of it as you progress with the cut. The tool should be supported as near to the business end as possible.

Withdraw the tool and move 0.050in. to the left for the second groove and repeat. Eight grooves are to be cut but remember that the last or top groove is only 0.040in. deep. When all the grooves have been cut, face the bottom face of the bottom groove with the left hand side of the form tool to complete the taper on the bottom fin. Leave the top of the top fin square with the cylinder since this surface mates with a rubber gasket on final assembly.

Cylinder bores

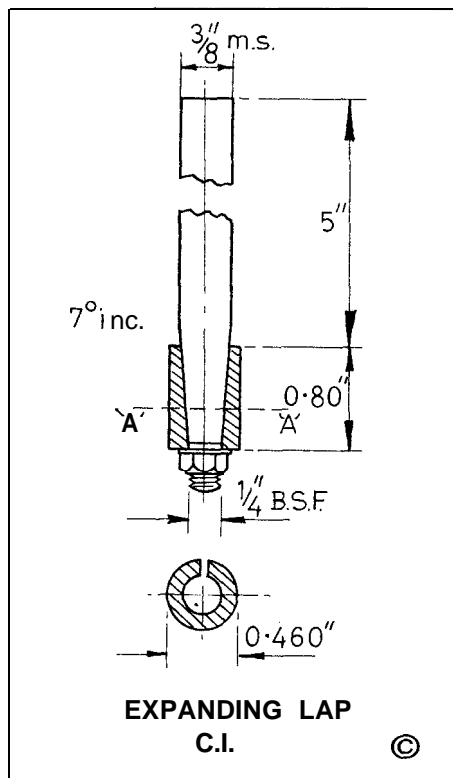
The cylinder can now be drilled to a depth of 3/4in. with a 7/16in. drill and then bored to a diameter of 0.458in. before finishing by honing or lapping. The tops of the fins should be rounded off with a needle file and polished with 1200 grit wet or dry paper. The finished height of the cylinder from the bottom face of the mounting flange to the cylinder head gasket face must be 0.646in., as shown on the drawing. Before parting off, the cylinder should be turned to 0.540in. above the top fin, and a tiny chamfer put in the lower end of the bore.

The 0.066in. dimension between gasket face and top fin is somewhat critical since, in the final assembly the 1/32in. thick spigot plate plus a 0.045in. thick composite rubber washer or gasket are installed on the top fin and squeezed

Despite our best efforts, the following dimensional errors escaped our scrutiny and have appeared on the printed page. We much regret any inconvenience which they may have caused.

*The rear 6mm dia. ball race journal for the crankshaft is shown on the drawing (ME. 16 June 1995, page 756) as 0.300in. long. It should be 0.300in. REF since its actual length will depend upon how accurately the rear bearing housing has been machined.

*The 7/32in. dia. rear camshaft journal is shown on the drawing (M.E. 21 July 1995, page 82) as 0.380in. long. It should be dimensioned 0.300in. REF.



between fin and cylinder head when the head fixing screws are tightened down.

The cylinder should be parted off 0.015in. over length at this stage since final machining to height will be done later. Part off the cylinder and make seven more to this stage.

The next job to be done is machining the flats on each cylinder to allow the cylinders to be mounted onto the crankcase. The drawing shows that removal of 0.033in. will enable the cylinders to be aligned onto the crankcase with a little clearance between each set of tins.

The machining is done by holding the cylinder in the machine vice under the vertical mill head. Clamp lengthwise between the jaws and mill along each fin in turn, not across the fins since this may tend to bend them. A tiny flat will also be milled on the mounting flange. The cylinders are ready for final lapping to size when all the flats have been machined and burrs removed.

Lapping may be a very dirty process but it is a fairly easy and straightforward job with a certain amount of satisfaction about it. Most builders will have their own methods and favourite materials for lapping so I will just explain how I finished my own cylinders. The lap shown in the drawing has proved itself on many of my cylinders in the past. It is simple and easy to make and use although for eight cylinders you may find it necessary to renew the split cast iron lapping head. Wear occurs during use, frequent adjustment of the head diameter is consequently necessary until ultimately the cast iron breaks at the split. If you are lucky, you may just manage to get it to last through lapping all eight cylinders but if it does break, making a new head is not a difficult job.

I used fine valve grinding paste mixed with oil for lapping. Make a 0.460in. dia. plug gauge from mild steel and lap each cylinder until the

gauge just enters at both ends, thereby ensuring a parallel bore. Bring all eight cylinders to the same stage before thoroughly cleaning the cylinders and the lap ready for final finishing using metal polish as a lapping compound.

Although the process is a bit long winded, I have found the method described above to be good enough to get the job done and to produce accurate bores. I was particularly fortunate in acquiring a Delapena hone two or three years ago, and have found this to be the tool to use. The hone doesn't produce a better finish than a lap but it does the job in a fraction of the time and can be relied upon to produce parallel bores rather more easily than when using a lap.

Whichever method you use, all the cylinders should now be at the same stage. The only work remaining is the final finishing to height, a job which cannot be completed until a spigot plate and a special fixture have been made.

Spigot plate

A piece of 1/32in. thick sheet steel will be required for the spigot plate. Anything sill do for this job-mild steel or gauge plate so long as it is perfectly flat and smooth. The piece should be cut to the outer dimensions shown and the edges finished by milling. Mark with a light centre line, put a small centre mark exactly halfway along the line and set the plate in the machine vice under the vertical head. The length of the plate should be parallel with the cross slide axis, i.e. at 90deg. to the lathe bed so that you can space out and drill using the cross slide movement as for the crankcase cylinder mounting faces.

The four cylinder and twelve fixing screw hole positions are next centre drilled using the same method as for spacing out and drilling the two cylinder mounting faces. The screw holes should be drilled No.43 and the cylinder positions drilled and bored from the mill head using a boring head. Alternatively, each position may be centred in the 4-jaw chuck and drilled and bored. The four bores should be an easy fit on the top diameters of the cylinders. Make two plates to this stage and finish them by rounding off the corners as shown on the drawing. Check that both plates fit the cylinders when they are mounted on the crankcase.

Some rubber washers are also required to fit the top diameter of the cylinders. These washers need to be 0.045in. thick. Half a dozen phone calls after much searching through Yellow Pages, I found a supplier of i.e. engine gasket materials who was prepared to sell me a square foot of heat resistant composite rubber sheet 0.045in. thick, exactly what I required.

I made a couple of punches and dies from EN16T cylinder off cuts and punched out a dozen very good washers under the drill press. They should be an exact fit on the cylinders and about 1/16in. wide.

A fixture is now required to hold the cylinders securely while they are being machined to height under the milling machine head. **Photograph 17** shows this fixture in use. A drawing of this fixture is hardly necessary since it is only a 4in. length of 1-1/4 x 1/2in. BDMS, drilled and bored as for the spigot plate, except that the four large

holes should be bored to 0.504in. dia., an easy fit on the cylinder skirt. The four holes should be bored to a depth of 1/4in., the twelve small holes should be drilled No.50 and tapped 8BA for a depth of about 1/4 inch.

Remove the work from the machine vice and clamp it to the milling table by its ends then, with a good sharp 1/2in. dia. end mill, take a minimum cleaning cut across the whole surface right up to the two end clamps. Clean the milled surface with a cloth, thoroughly clean the lower faces of the cylinder flanges and sit four of the cylinders on the fixture making sure that there is a tiny amount of clearance between the flats on the tins to enable each cylinder to sit squarely on the milled surface of the fixture. Fit a rubber washer to each cylinder and then fit a spigot plate. Screw the plate down with twelve long 8BA screws until the rubber washers are compressed. Secure the cylinders to the fixture, tighten the screws evenly taking care not to bend or distort the plate.

Now for the tricky bit, fit a sharp or even a new 3/16 or 1/4in. end mill to the mill head collet and apply a 0.005in. cut to the top of one of the cylinders then, using leadscrew and cross-slide feed movement, follow the annular surface round making sure you avoid the screw heads. Machine all four cylinders at the same setting before applying a further cut. Keep to a maximum of 0.005in. per cut and finish with a 0.002in. cut. Use a depth gauge to ensure that the final height of 0.646in. is correct. The set up is quite secure enough for the small cuts being taken but it would be a good idea to reduce the diameters of the screw heads to a minimum, reducing the chance of the cutter touching the heads and suddenly unscrewing the 8BA thread!

Remove the four cylinders without disturbing the fixture then, before you do anything else, mark the cylinders 1, 3, 5 and 7 by putting tiny centre pop marks on the small flats that were milled into the mounting flanges. This identifies these four cylinders as having been machined together and are therefore all of identical height. They are also the starboard (right hand) bank. Repeat these operations on the other four cylinders using four new rubber washers, mark the second four 2, 4, 6 and 8. These are the port (left hand) bank. Since they are the final gasket faces, the annular faces should be treated with care from now on and should not be touched with any sort of abrasive material. They will finally be pulled down onto soft aluminium gaskets to seal the combustion chambers.

The cylinder mounting face bores have been made 0.004in. larger than the cylinder skirt diameters to allow the cylinders to maintain their upright alignment by sliding against the cylinder mounting face when the crankcase expands with heat. The cylinder head will also expand and will slide against the spigot plate interface and the annular surfaces of the tops of the cylinders. The 8BA fixing screw threads may just clear the fins when inserted through the spigot plate. If they don't, mark the positions of the fixing screws through the spigot plate onto the tops of the top fins and either file or use a 3/32in. dia. ball nose cutter to machine clearance into the banks of fins.

To be continued.

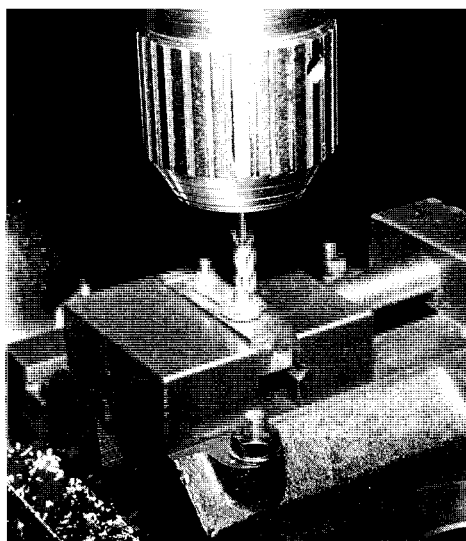
V8

Fourstroke Aero Engine

Eric Whittle

explains how to make the connecting rods with their bronze shim bearing shells for his 10.6cc air cooled glow plug aero engine.

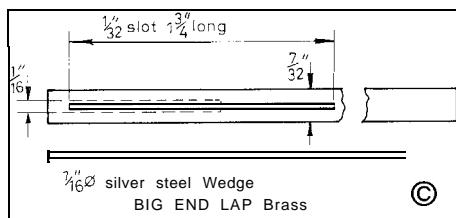
- Part VI continued from page 208 (18 August 1995)



Profiling the connecting rods is facilitated by the use of a simple but accurate milling fixture. A sharp end mill run at correct speed will provide a good machined surface finish.

Fit a 3/32in. dia. milling cutter and counterbore each hole to a depth of 0.11 Oin. before traversing the cutter to the edge of the workpiece at the 0.11 Oin. depth to produce the cavity as shown in the end view of the bearing cap.

Bring the other seven blanks to the same stage and tap all 16 holes 10BA. Be careful with your tap because you are working in a blind hole.



Big end caps

The cap is split from the main rod with the aid of a 1/32in. (or thereabouts) slitting saw. Fit the saw into the milling machine head and set a blank upright once more in the machine vice, cap end uppermost. Set the blank at the appropriate end of the vice to ensure that the slitting saw mandrel does not foul the jaws. To do this safely, it will be necessary to grip another blank at the other end of the jaws to keep them parallel when tight. Ensure that the blank is properly upright and touch the bottom surface of the saw on the top of the blank. The old toolmaker's trick of tearing a tiny fragment from the corner of a cigarette paper and sticking it with a little moisture onto the surface of the workpiece is a good one to use here. Set the saw blade running and ease the workpiece towards the cutter.

Sooner or later the cutter will flick the piece of paper from the workpiece. If you have measured the thickness of the paper (about 0.0015in) you can allow for it and set the vertical head feed screw to zero when the saw blade is dead in line with the top of the embryo rod.

Assuming that your saw blade is 1/32in. thick (0.032in.), lower it $0.175 + 0.032 = 0.207$ inch. Before sawing off the top 0.175in. mark the side face of the blank with a couple of scribed lines on to identify which way the cap will be mated to the rod. Carefully saw it off and, to prevent the wrong cap being paired with the wrong rod, temporarily fit the cap to the rod with a 10BA screw.

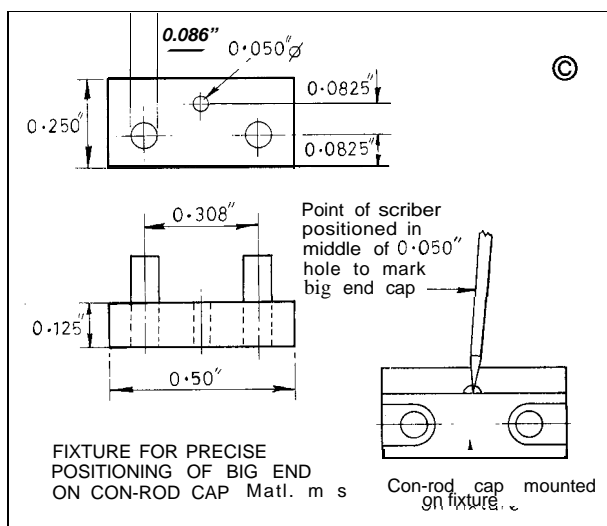
Bring the other seven rods to the same stage.

Screw the caps to their respective rods with two pieces of 0.005in. shim bronze sandwiched between cap and rod to enable you to bore the rod to the correct diameter for the bearing shells. I used a rod and cap as a drilling jig to produce 16 pieces of bronze packing, if you follow suit do make sure you get rid of the burr round the 10BA clearance holes. It is important that the packing pieces are perfectly flat before being sandwiched between cap and rod and each pair should take up no more than 0.010in. thickness.

Boring for the big end shells

When all the rods and caps are assembled together with their packing and the screws tightened, there is likely to be some excess bronze packing protruding all round the joint. If this is so, one of the front faces must be cleaned up flat and smooth so that the centre of the big end bearing can be marked out. For this, a special marking aid is required to ensure that the centre mark is positioned correctly.

Study of the drawing and a little work with a pocket calculator will reveal that there is only a touch over 0.011in. between the 10BA screws and the surface of the crank pins. This means that we must be very precise in positioning the centre mark before boring. My drawing shows how to make and use a little marking jig. When fitted to the cap blank, using an eye glass the point of the scriber should be placed in the middle of the half round part of the hole still visible. Obviously the smaller the hole the more precisely the scriber mark can be positioned. Use good back lighting to silhouette the scriber point in the half round of the hole.



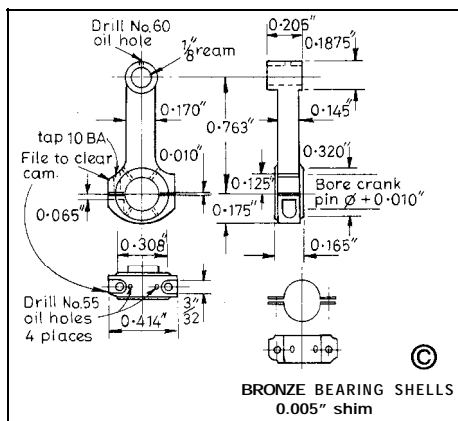
Connecting rods

The connecting rods are made from HE15 light alloy and are fitted with bronze bearing shells. Over many hours of running with three different engines and the wet sump charged with 5cc of GTX (or similar) oil, this has proved to be a good combination with the EN16T steel crank pins. If needs be, the bronze shells can also be easily renewed.

To improve our chances of ending up with eight identical rods, simple jigs will be used for most of the machining operations. We will need to start with eight slightly oversize (0.30 x 0.45 x 1.25in.) blanks of HE15 alloy

Set a blank upright in the machine vice and mark the centre of the end surface with a small pop mark. Two diagonal lines scribed from the corners will give an intersecting point which is where the pop mark should be. Centre the pop mark under the milling machine head with the aid of a 1/8in. dia. silver steel centre point. Remember to account for backlash in the leadscrews. Move the work 0.154in. towards one end of the rectangular surface and centre drill. Note the feed screw reading then move back 0.308in. (accounting for backlash) to centre drill for the other big end bolt. Note this feed screw reading.

Replace the centre drill with a No.55 drill and, using the previously recorded feed screw readings, drill each position to a depth of 3/8 inch. These are for the bearing cap fixing screws and will be tapped 10BA. Now fit a No.51 drill and drill each position to a depth of 0.200 inch.



When the mark has been scribed on the cap blank, screw the cap to the rod complete with the appropriate bronze shims and scribe a line parallel to the length of the rod through the mark and across the edges of the bronze packing pieces. The intersection of the line and the mating faces of the shims is the point where the centre mark should be positioned for drilling and boring the big end. While you are at it you might as well mark all eight rods prior to setting up for boring!

When all this is done each rod can be set in the 4-jaw chuck and the centre mark set to run true. Centre drill and drill to 3/16in. diameter. If all four crank pins have been finished to exactly the same diameter of 7/32in., this task will be fairly easy since all eight big ends can be bored to the same diameter of 0.229in., crank pin diameter plus the thickness of the two packing pieces. If there are any slight differences, the rods will have to be bored to fit their particular crank pin diameters plus 0.010in. and then identified with those crank pins.

Bearing shells

The bearing shells can now be made and fitted. Each rod will require two pieces of the shim bronze cut to about 1/16in. wider than the width of the rod and about 5/8in. long. Before starting on making and shaping the shells, remove the sharp edges inside the big end bores created by the saw cuts—four edges per rod. If these sharp edges are not removed they may cause stress in the shells or sever them when being formed or later when the engine is running, and the lug(s) could be broken.

Two of the cut lengths are bent into a U-shape around a piece of suitable size bar before being pressed into the rod half and held there with a piece of 7/32in. dia. silver steel while the ears or lugs are bent outwards. Both pieces are treated in a similar manner. If the crank pin is 7/32in. dia. then a piece of 7/32in. silver steel can be used to form the shells by clamping in the machine vice.

Assemble the rod and cap with the shells into the vice gripping lightly across the ends. Insert the 7/32in. dia. steel form piece, align everything and tighten the vice. Remove from the vice carefully and identify the positions of the two shells relative to the cap and rod. Reassemble once more by gripping across the ends with a toolmaker's clamp, arranging the clamp to clear one of the 10BA screw holes so that the lugs of the shells can be drilled through for 10BA clearance using the cap as a drilling jig. Be careful only to go through the bronze shells and not into the 10BA tapped hole in the rod. Fit a 10BA screw

and repeat the operation on the other side.

Bring all eight rods to the same stage.

Remove the burrs from the holes in the bronze shells so that the ears or lugs can be clamped perfectly flat on final assembly to give the correct big end bearing diameter. Remember that any differences in crank pin diameter must be accounted for by making the steel form piece the same diameter as the relevant crank pin. Each pair of rods must, of course, be identified with the correct pin.

Excess shim material should be cut off with a pair of scissors and may then be left since the rest will be machined during profiling of the rod in the lathe.

Little end bores

The next job is to position, drill and ream for the little end or gudgeon pin hole. This is best done using a simple jig held in the machine vice under the vertical milling machine head. A 2in. length of 1/2in. square steel is required for this jig. Hold it in the vice aligned lengthwise parallel to the milling machine table feed screw. In my case this was the cross-slide feed screw. A 1/4in. dia. hole is drilled and reamed at one end of the piece of steel and the feed screw dial set to zero. The work is then moved through 0.763in. ready to drill and ream a 1/8in. dia. hole towards the other end of the work piece. Turn a 3/4in. length of mild steel so that half its length is 1/4in. dia. and the other half is the crank pin diameter. Fit the piece into the 1/4in. dia. reamed hole with Loctite and drop a rod blank onto it. Align the rod with the jig and tighten the 10BA screws. The little end can then be drilled and reamed 1/8in. diameter.

Repeat all these operations on the other seven rod blanks, but remember that if the crank pin diameters vary, further locating pins will be required to suit. After drilling and reaming the gudgeon pin holes, the jig and any extra locating pins should be set safely aside for they will be needed later to mill the front profile of the rods.

The dimensions of the rods have been arranged to take account of the 0.020in. offset between the vertical centre line of the rod and the centre line of the cylinder caused by the 1/8in. displacement between the left and right hand cylinder banks. The little end bearing has been extended or offset to take care of this and to ensure no significant part of the gudgeon pin remains unsupported.

Profiling

The rods can be faced to size next. To save making more spigots, the jig locating pins could be used to hold the rods in the lathe for the facing operation. Whichever way you do it, a crank pin sized spigot should be held in the collet or chuck and the rod mounted to it. With the big end screws tightened up, the rod can now be faced to the dimensions shown on the drawing. Be sure to keep the 10BA screw positions in the middle of the width of the rod and only face up to within a 1/16in. of the gudgeon pin holes. Using, a 1/8in. tapered spigot, these will be faced in the next operation.

While the 7/32in. spigot is still in the lathe the 0.010in. deep relief can be faced in on each side of the rods.

Turn a 1/8in. spigot with a slight taper on a suitable piece of material and push a rod on tightly enough to turn and face the little end to the dimensions shown on the drawing. When all eight rods

have been brought to the same stage, the 1/2in. square steel jig can be reset in the machine vice for profile milling the front view of the rods.

Shaping the rods is a fairly straightforward job, see **photo 19**, but the 1/4in. and 1/8in. dia. holes must be carefully aligned true with the movement of the milling table to avoid tapered rods. Fit a 1/8in. silver steel spigot into the 1/8in. reamed hole in the jig, fit a big end spigot into the 1/4in. reamed hole and mount the rod onto the jig, pushing it down as far as it will go. Fit a 7/32in. dia. end mill to the milling machine head and profile one side of the rod to the dimensions shown on the drawing. Note the index dial settings as you go. To ensure symmetry of the rod, turn it over to machine the other side. The apparently unmachinable bit at the top of the rod between the little end bosses can be shaped away later using a side mounted parting tool and fore-and-aft saddle movement, the work being held on a short 1/8in. dia. spigot and turned a degree or two at a time between the shaping cuts.

Be fairly precise with the 0.125in. dimension of the height of the big end shoulder. Make both sides the same at this stage, one of the shoulders will be reduced in height later when the rods come to be fitted to the crankshaft. Four oil holes are drilled in the big ends as shown. This will assure a good supply of oil to the big ends when the engine is running as there will always be one or more holes ramming into the oil mist prevailing inside the crankcase. A similar hole is drilled in the little end bearing at the top of the rod. The back of the big end cap is tiled to the shape shown on the drawing.

Lapping the big end shells

At this stage, the rods can now be lapped to the crank pins. If you fit a rod to its appropriate pin and tightened up the big end you will probably find it too tight to turn by hand. This can be corrected by using the split brass lap shown in the drawing. Use the lap sparingly with fine valve grinding paste until you can turn the rod by hand when fitted to the crank pin. You may have to have two or three goes before obtaining the right sort of fit. Most importantly, make sure you wash off all traces of the grinding paste from the big end bearing before fitting to the crank pin each time.

When the fit is such that you can turn the rod by hand, complete the process by hand lapping the bearing onto the crank pin itself using metal polish and oil. This is a somewhat tedious and wrist aching business but it needs to be pursued until the rod can be turned on the pin with just slight drag. All eight big ends must receive this treatment before being thoroughly cleaned and refitting with oil. Don't be tempted to use the lathe for the final part of the lapping, the eccentric action of the crank pin makes the job awkward and not a little dangerous.

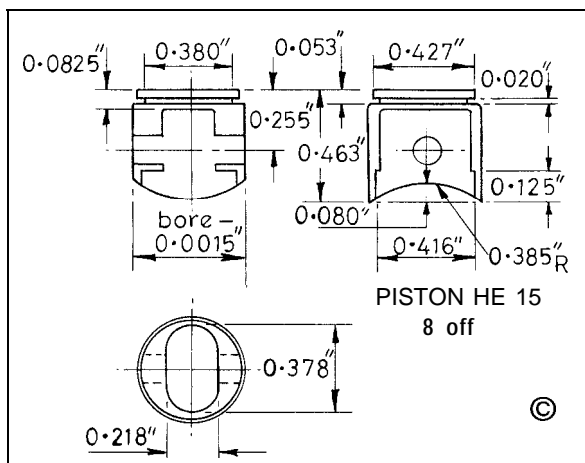
On the first run of the new engine, the big end bearings will fit so closely that oil is unlikely to be able to penetrate effectively and some 0.002in. of wear will occur during the first half hour of running. This clearance will permit ingress of the hot oil into the bearing and the rate of wear will fall dramatically. After some three hours running, I cannot detect any increase in the original 0.002-0.0025in. of play which had occurred in the first 20 minutes on my own engine. **To be continued.*

V8

Fourstroke Aero Engine

Eric Whittle
describes how to make the pistons
and gudgeon pins for his 10.6cc air
cooled aero engine with glow plug
ignition.

*Part VII continued from page 361
(15 September 1995)*



Pistons

The pistons are made from HE15 aluminium alloy and, apart from the radiused cut-outs on the skirts to clear the crankshaft webs, are fairly straightforward. The only HE15 which I could obtain was 1/2in. square section which involved me in an extra 4-jaw chuck operation.

Start by sawing or parting off eight pieces 1-1/2in. long. Mount the first piece in the 4-jaw chuck and centre carefully. With the pistons at 0.460in. dia. there is little room for error. Face the end and reduce to 1/4in. dia. for 3/4in. then drill and tap the end 2BA for a depth of 1/2 inch. This will enable it to be secured to an angle plate to machine the curved crank web clearances later. Bring all eight pieces to the same stage.

Now hold each work piece by the 1/4in. dia. spigot and turn the 1/2in. square to about 0.490in. dia., just enough to clean it up. Positioning, drilling and reaming the gudgeon pin holes is the next job. Since I do not possess a tailstock V-pad which might have made the job easier, I carried out this operation under my vertical milling head. Mount the work piece in the machine vice under the mill head, use a DTI to align the piston truly horizontal (**photo 21**), fit a 1/16in. cutter and mark the piston blank where the gudgeon pin

hole is to be placed. With the cutter placed over the mark, using the same technique as for finding the centre of the 18 tooth gear key hole in the crankshaft, a tiny rectangular flat can be cut onto the piston. The centre of the flat is marked and the 1/8in. centre used to centre it truly under the milling spindle. Once in place it is then centre drilled, drilled and reamed through 1/8in. (**photo 22**). The process is repeated for the other seven pieces.

The piston skirts can now be bored to a diameter of 0.416in. for 1/8in. depth. This is done using a 7/32in. slot drill from the tailstock to bore into the end of the blank until the slot drill has passed right through the gudgeon pin hole. The skirt can now be faced to length by fitting a dummy gudgeon pin and measuring from the skirt to the bottom of the gudgeon pin with a depth gauge. My drawing shows that this dimension should be 0.1455 inch.

After boring the skirt, use the slot drill to finish the 7/32in. dia. hole to a depth of 0.380in. from the bottom of the piston. Check all the quoted dimensions from the drawing. Bring the other seven blanks to the same stage.

The 7/32in. wide elongation must next be machined to take the conrod little end. This is done under the milling head by gripping the piston blank in the machine vice by its spigot (**photo 23**). Insert a length of 1/8in. dia. silver steel into the gudgeon pin hole and align it with the lathe bed to ensure that the 7/32in. slot is exactly perpendicular to the gudgeon pin. Fit the 7/32in. slot drill to the milling chuck and centre it to the 7/32in. dia. hole in the piston. The drawing shows that the cutter must be moved about 0.080in. either side of the centre position to produce a 0.378in. long slot. For this to be

done with any real accuracy, free play or backlash in the feed screw must be taken into account. In my case, using the VMA attachment, this involved the cross-slide feed screw. Note the dial index positions when the cutter is at the ends of the slot and use these readings when machining to the 0.380in. depth of the existing 7/32in. dia. hole. Since it is difficult to see what is going on due to the end of the piston being filled with swarf, you will be working blind, but provided you had the dimensions and the dial readings right in the first place everything will work out satisfactorily. Once again, bring the other seven pistons to the same stage.

Final turning to size is the next job. If all your cylinder bore diameters are identical then you can go ahead and make all eight pistons the same size, 0.0015in. smaller than the bore diameter. If you haven't managed to achieve this feat (and I for one never have), then you will have to identify each piston with its cylinder. I always find it to be a problem to get the right piston diameter since I have no small bore internal measuring device. I manage by turning the piston to an easy push fit in the cylinder bore and then polishing it to exact size with 1200 wet or dry paper backed with a 6in. steel rule. Since I don't know the

exact size of the bore, I can't turn and polish the piston to an exact size, however, and the only way I know of dealing with this problem is to use a 0.0015in. feeler gauge. If the first 1/4in. of the tapered tip of the feeler is inserted into the bore together with the piston, it should be possible to remove it with a slight drag. When this situation has been achieved, the piston is of the correct diameter.

Having made a number of the same size cylinders, I have found that anything less than 0.0015in. clearance causes the cylinder to run hot. The effect is cumulative, the heat causes expansion which creates more friction which in turn creates more heat and so on until the power loss is so great that the engine stops! 0.0015in. clearance seems to be just about right.

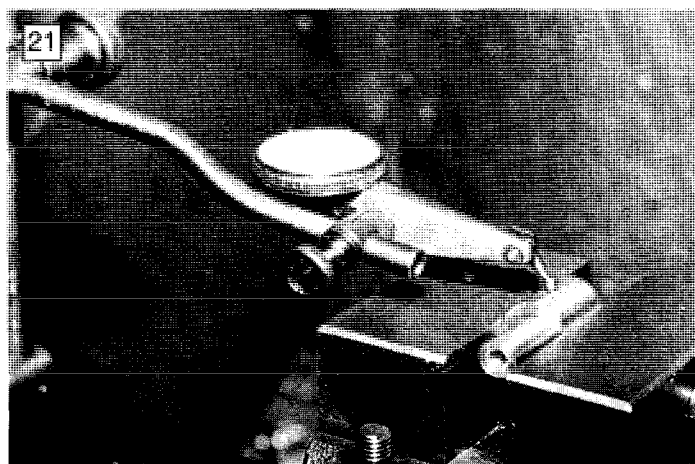
When all the pistons have been sized in this way they can be identified with their individual cylinders by marking them on one of the two flat areas over the gudgeon pin bosses. These marks will also identify the front of the pistons so that they can always be assembled correctly after having been removed, most important once the engine has started its running life.

The curves on the skirts can now be considered. There are two ways of machining these curves. One would be to mount the piston on an angle plate on the face plate, set the gudgeon pin hole parallel with the lathe bed using the length of 1/8in. dia. silver steel as before, then offset the piston the correct distance from the spindle centre line and bore the curves into the skirts but I did mine differently. I put a boring tool in the 4-jaw chuck and held the piston on the vertical slide (**photo 24**).

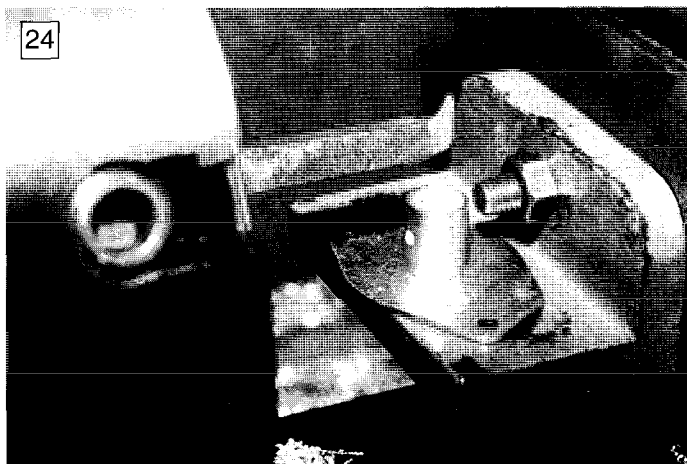
Before machining the piston skirt, it must be marked to determine the exact amount to be removed. This can be done by fitting a conrod to the crankshaft and a piston to the conrod. Set the rod and piston to be in the bottom dead-centre position and find how far up the outside diameter of the skirt the 3/4in. dia. crank web comes. A centre mark can then be made on the O.D. of the piston skirt at this level to show the point to which the curve must be machined and enable the web to clear the skirt in operation.

The awkward part of the set up shown in the photograph was setting the boring tool to cut the correct radius curve. After much deliberation, I decided on the following method. Turn a short piece of 1in. dia. mild steel bar to 3/8in. dia. for 1in. length, reverse it in the chuck, centre drill, drill and bore the 1 in. diameter end to 11/16in. dia. for a depth of 1/4 inch. Hold this in the tailstock chuck by the reduced diameter and bring it up to the boring tool now set in the 4-jaw chuck so that the cutting tip just grazes the inside of the 11/16in. dia. bore. Adjust the tool to take a skimming cut from the 11/16in. bore, feeding from the tailstock hand wheel. Set a pair of toolmaker's calipers to 0.770in. using a micrometer and check the bore diameter, adjusting the tool until the bore reaches 0.770 inch. The tool is now set correctly for machining the piston skirt curves.

The rest of the set-up is as shown in the photograph. The piston is held to the angle plate by a 2BA screw and washer after the piston has been aligned using the length of 1/8in. dia. silver steel as described previously. Position the work as nearly as you can under the centre line of the



21: The embryo piston is set truly horizontal with the aid of a dial gauge before drilling and reaming the gudgeon pin holes.

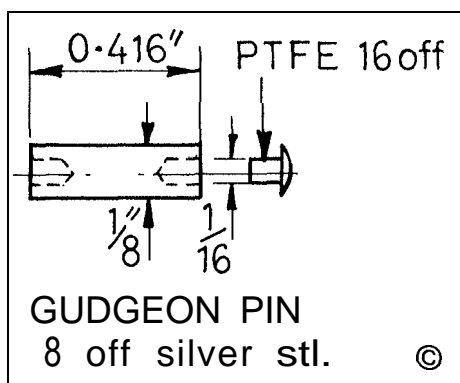


24: Having previously set the boring tool to the correct diameter, the piston skirts are machined to provide clearance against the crankshaft.

lathe spindle, then bring the work up until a small cut is taken from the skirt. Go right across both sides of the skirt to reveal just how accurate is the vertical alignment (or otherwise!) of the piston under the swing of the tool. As the cuts continue, the two parts of the annular bottom surface of the skirt will become smaller, making it easier to judge and correct any misalignment with small movements of the cross-slide. Take the cut to 0.010in. below the centre mark made earlier to allow the skirt to clear the web by that amount.

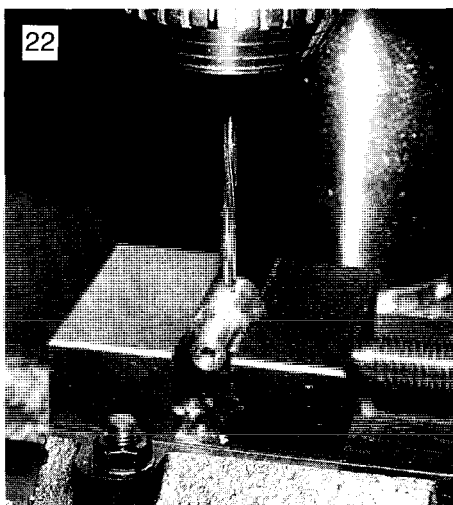
I reckon that this method is probably easier and more controllable than that previously described. I'm sorry about this, but you must now bring all seven of the remaining pistons up to the same stage—all part of the grind of multi-cylinder engines.

The pistons are completed by sawing or parting off the 1/4in. dia. holding spigots and facing each to length, preferably holding them in a collet. I used my 1/2in. dia. lever collet with cardboard packing to centralise the piston and to protect the polished surface. A temporary gudgeon pin will require to be fitted to determine the correct faced length. A small piece of 1/8in. square silver steel packing will also be necessary between the bottom of the gudgeon pin and the anvil of the micrometer to enable the distance between the piston crown and the gudgeon pin to be measured. This should finish at 0.3175 inch. Endeavour to get this dimension right on all eight pistons since it will affect the uniformity of the compression ratios. Put another way, if there is one, they should all have the same error!

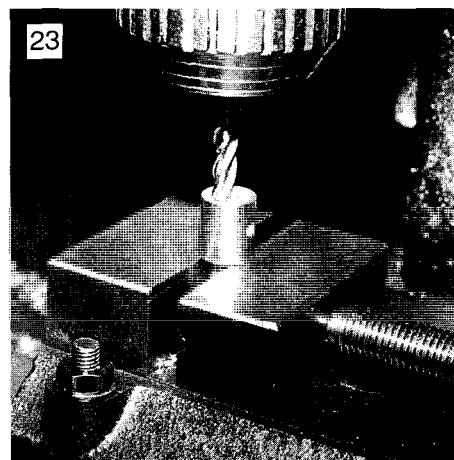


Gudgeon Pins

The gudgeon pins should be made next. After all that has gone before, they are pretty straightforward items. In fact, making the PTFE end



22: A 1/8in. dia. reamer is required for finishing the gudgeon pin hole to size.



23: The internal profile of each piston is produced by milling. Swarf hides most of the work and reliance must be made on careful use of pre-determined index dial settings.

pads is more of a pain than making the pins!

Make the pins first and drill the ends 1/16in. dia. for a depth of 1/8in. Hardened them, temper to light straw and re-polish. The end pads are turned to a tightish fit in the end holes. Turning PTFE to very small diameters is a bit like turning suet pudding but it can be done if the tool is dead sharp and the lathe is run at a high enough speed. When the end pads are fitted into the gudgeon pins they can be rounded off in the lathe with a needle file.

Ring grooves

Ring grooves can now be machined into the pistons in preparation for making and fitting the rings. A concentric spigot to fit the 0.416in. dia. of the piston skirt is required for this operation. The piston mounted on the spigot and secured with pressure applied through a pressure pad from the tailstock. The pressure pad can be a disc of light alloy of about 0.400in. dia. and 3/16in. or so wide, faced smooth on one side and with a 1/8in. centre hole drilled in the other.

Make sure that the piston is sandwiched between the crown and the surface forming the gudgeon pin bosses, and that the skirt is a snug fit on the spigot or mandrel. Apply a touch of graphite grease to the face of the aluminium pad.

Grind a 0.020in. wide parting (grooving) tool to cut the ring groove to a depth of 0.040 inch. After machining the groove, reduce the crown diameter to 0.427in. with the same tool.

Remove the sharp corners and repeat for the other seven pistons.

Adjustments

Before we go ahead and make the rings it is best to assemble the engine, complete with rods, pistons and cylinders, to determine how much and from where material must be removed from the big end shoulders to clear the cylinder skirts and the cams. On assembly it will be seen that everything is rather tight for space and it is highly likely that several of the con-rod shoulders will foul adjacent cams. Over-long big end screws can also catch the bottom of the cylinder skirts. My con-rod drawing shows where the rod should be reduced with a needle file to cure the problem. The best way is to deal with them one at a time. By removing the other seven, you will be sure of what you are trying to do. Having cured one you will have a good idea what must be done to sort out the others. Due to the necessity of removing the rod assembly each time an adjustment is made, this is one of the slowest and most tedious jobs on the engine, but it has to be done.

When all the rods have been dealt with and the engine can be turned over, the importance of identifying which way round the rods must be fitted becomes apparent. They should be marked accordingly at this stage since much dismantling and assembling remains and I wouldn't want you to get them all mixed up! *To be continued.*

V8

Fourstroke Aero Engine

Eric Whittle

describes the manufacture, heat treatment and fitting of the piston rings for his 10.6cc aero engine and explains how to set the timing.

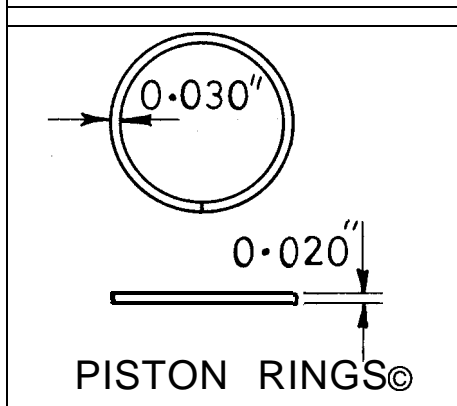
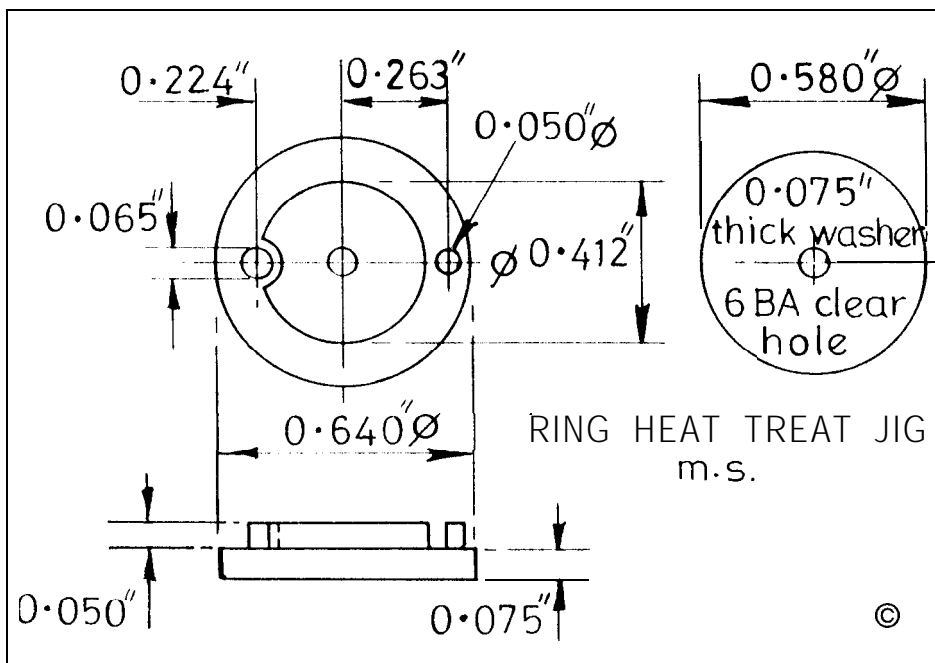
● Part VIII continued from page 489
(20 October 1995)

Piston rings

The next items to be tackled are the piston rings. I made mine from close grained cast iron obtained from A.J.Reeves of Marston Green. Unfortunately I could only get lin. dia. material, 1/2in. dia. would have been ideal. The rings were made using a method devised by George Trimble of the U.S.A. and described in detail in *Strictly I. C.*, an American magazine. The rings produced by this method fit the bores correctly from the word go with the minimum of running in. To allow for breakages or other accidents or incidents, I made three rings per cylinder. If all eight bores are identical then here again only one ring blank need be turned and polished to size. This, however, is unlikely and more than one blank will probably be needed.

Start by making a blank for the largest diameter bore. Use a mild steel plug gauge to find the biggest bore, turn and polish the ring blank to size for a length of 1.5in., using 1200 grit wet or dry paper. Aim for an easy push fit in the cylinder. Bore the inside diameter to 0.400in. to ensure that the ring will not bottom in the ring groove when installed in the cylinder. Three rings can now be parted off to a width of 0.022in., but before the ring is completely removed from the stock material, remove the sharp corners with a fine needle file. Identify the rings with the cylinder and continue to make the rest of the rings for the other cylinders. The rings can be kept on a piece of wood fitted with eight dress pins and numbered 1-8 on the wooden base. There is little more frustrating than not being sure if you have picked up the correct ring.

The rings must now be broken dead square in both planes. This can be done with the aid of a pair of good quality pincer type wire cutters, sometimes known as end cutters. It is very important that the cut ends are square because stressing after fitting to the heat treatment jig must be along the neutral axis of the ring, i.e. the imaginary circle midway between its I/D and O/D. If these conditions are met, the ring will be perfectly round when closed up after heat treatment. If the conditions are not met and the break



is out of square, when installed on the jig the gap could be held open by one I/D corner and one O/D corner. In this case, the ring would not be round when closed after heat treatment. The jig has been designed to provide perfect rings from the outset requiring next to no running-in.

After cutting the rings, the rough crystals of iron should be cleared out of the gap before the rings are fitted to the jig. My method for this is to mount two 2in. dia. discs of 1200 wet or dry paper back-to-back on my No.2 Morse taper slitting saw mandrel, then fit a makeshift saw table to the four post tool holder—a piece of 3/4 x 1/8in. steel with a hack saw cut in the end will do. Set the saw table to centre height and get the abrasive discs into the saw cut, opening the ring sufficiently to get it on the discs. Position the ring in line and keep it pressed down to the table, then turn on the lathe and immediately withdraw the ring from the rotating discs. Remember that we are not trying to introduce a gap, we are only cleaning out the crystals of iron, so the ring must be on the discs for only two or three revs. Treat all the rings in this way and be sure not to get them mixed up.

Heat treatment jig

Simple and easy to make, all that is important

about the heat treatment jig is its dimensional accuracy. It has been designed to take three rings at a time. Carefully install three rings and clamp with a 6BA screw and nut. Bring the whole assembly to bright red heat using a propane gas torch and allow to cool in still air. Carefully remove the rings from the jig and return two of them to their identification pins on the wooden base.

For the rings to fit the pistons they must be reduced to the piston ring groove width of 0.020 inch. This is probably best done by rubbing them on a sheet of 1200 wet or dry paper on a flat surface such as a surface plate. I use a piece of thick rubber cut from an old conveyor belt to press down on the ring to spread the pressure and reduce the wear on my fingers while abrading the ring. Reduce its width until it fits easily into the piston ring groove and be sure that it is of uniform width all round. When this has been done, the ring can be gapped on the wet and dry discs, this time by lightly closing the gap onto the rotating discs and moving the ring back and forth a few times to make the gap. Remove the ring from the discs and fit it into the cylinder to check the gap with an eye glass against a strong light. The minimum gap you can see is the gap you want! If the ring can be pushed easily along the length of the bore with minimal friction, using the piston to push it, you may consider the job to be done. It can now be fitted to the piston.

Obviously, the ring should be carefully fitted to the piston, but it should go on fairly easy using fingers and thumbs. Carefully open the ring the least possible amount to get it over the smaller diameter of the crown, then press it down gently and evenly until it snaps into the ring groove.

Assembly

To fit the piston to the cylinder, stand the cylinder on the bench and fit the piston skirt first into the top of the cylinder and push it down to the ring. Using the ends of two 6in. steel rules,

press lightly on the sides of the ring to close the gap. When the gap is closed, press down hard on the piston crown with your left thumb and use the steel rule to press lightly on the side of the ring while rotating the cylinder. Maintaining downward pressure on its crown, the piston will suddenly shoot into the cylinder. Push the piston to the bottom of the cylinder and rotate the piston skirt which should turn easily if the ring fits the groove correctly without bottoming.

Be careful not to mix the rings up. A small ring when fitted into a large bore will not be perfectly round. The same applies when a larger ring is gapped to a smaller bore. The rest of the rings can now be fitted and assembled to the cylinders.

To assemble the piston and cylinder combinations to the crankcase, all the con-rods should be fitted and the gudgeon pins removed and the pistons pushed down the cylinders until the gudgeon pin holes are just below the bottom of the cylinder. The piston and cylinder are carefully lowered onto the little end and the gudgeon pin pushed in, the cylinder is then pushed down to the cylinder mounting face

Final fitting of the con-rods to the crankshaft is done with high tensile screws made from bits and pieces of EN16T. I have found that most commercial 8 and 1 OBA screws tend to be too easy a fit to make good big end screws, so for the sake of peace of mind I go to the extra trouble of making well-fitting shake-free screws, then fitting them with Loctite 222 Screw Lock. The threads are made with the 10BA die opened to maximum diameter which is then closed bit by

bit until a slightly tight, shake-free fit is obtained in the con-rod thread. The heads are turned to 0.090in. dia. and a 0.010in. wide screwdriver slot is cut in each with a slitting saw on a mandrel in the lathe. One end of a 2in. length of 1/4in. square mild steel is drilled and tapped 10BA and the screw fitted tightly with the aid of a pin vice. The square steel is then mounted at centre height in the tool post to cut the slot. Cutting suitably sized pieces of EN16T is a bit of a pain so, if you prefer, high tensile cap head Allen screws could be used instead.

Timing the engine

Now that sufficient of the engine is assembled, we can have a go at the timing. Although there are eight cylinders, we only have to get one timed correctly and the others will fall into place. Timing is arranged by putting the No. 1 cam pair in the zero angle position. This is the position where there is zero angle between the two cam flanks at crankshaft top dead centre. Had the engine any overlap, which it does not, this would be the valve overlap position.

The position is easy to find by pressing down on the two No.1 cylinder cam followers and turning the camshaft until both followers are in their lowest position and the camshaft cannot be rotated either way without lifting one or the other. This is the position at which the camshaft must be set when the crankshaft is at TDC for No. 1 cylinder. The easiest way of achieving this condition is to lock the crank-

shaft at TDC for No. 1 cylinder by removing the propeller drive plate, threading a suitable washer onto the front of the crankshaft, replacing the drive plate and securing it with a 3/16in. X 40tpi nut.

Set the TDC position by checking the angle between one of the sides of one of the crank webs and the flange face of the crankcase top half. The angle should be 45 degrees. I stuck a piece of 1/8in. square steel to the crank web with Araldite then packed the case up on the surface plate using V-blocks. The crankshaft was rotated until the piece of square steel was in the 45deg. position and the angle checked by sliding a 45deg. template gauge up to it. The crankshaft nut was tightened with no more than finger pressure and TDC was set.

The camshaft gear is now removed and the No. 1 cam pair set and held in the zero angle position as previously described. A touch of Loctite 601 is applied to the camshaft gear seat and the gear replaced and held down with slight clockwise pressure to remove any backlash in the gearing. When the Loctite has set, apply a little Screw Lock to the 8BA cap head and tighten it. Now rotate the crankshaft until the gear tooth which is in line with the key way on the 18T gear is meshed with the camshaft gear. Lock the crankshaft again and put a centre dot on the two camshaft gear teeth which are either side of the in-line keyway tooth on the 18T gear. The camshaft can now be removed and replaced correctly.

**To be continued.*

Reader Lewis Throop in California, USA wrote to author Eric Whittle on the matter of suitable materials for this engine. We publish part of the author's response for the interest of other builders and readers.

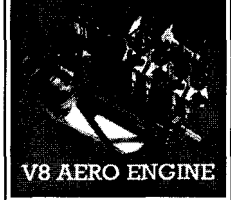
I realise that EN classification numbers for steels were phased out some twenty years ago, but they are still used in industry and are used in contemporary engineering literature. Old habits die hard! The new British specifications to BS 970 of 1970-73 is 605M36. The helpful gent on the other end of the 'phone at the steel stockist which I rang looked in his book and told me that a close American equivalent would be SAE 4340 which, like EN16T, is a nickel-chrome steel. I feel it is important to use a fairly close equivalent since less tough steels have proved to wear rather badly. The crankshaft and cylinders are not heat treated and are used in the as-supplied condition.

You will, of course, appreciate that other steels would be suitable, were it intended to heat treat the parts to a suitable hardness. The steel which I have used required no heat treatment and building the engine was therefore more straightforward, there being no worry regarding distortion of the parts during hardening. It may also be that there are slight differences between types with the result that an American spec. steel may perform differently to an 'equivalent' British spec. material.

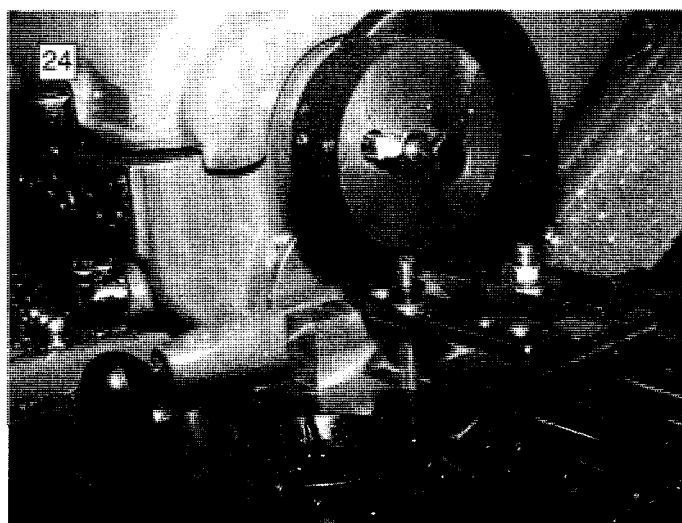
Someone in your neck of the woods who would probably be able to help with equivalent spec. numbers and the actual supply of the materials is Bruce Satra of Vernal Engineering Co, 2277 S. 1500 West, Vernal, Utah 84078, U.S.A.

To date, my engine has run for some 9-10 hours and the big end wear has not increased beyond than the 0.002in. which appeared in the first 20min. of running. This brings me to the conclusion that after much experimentation and trial and error, I have chosen the appropriate combination of materials for these important components.

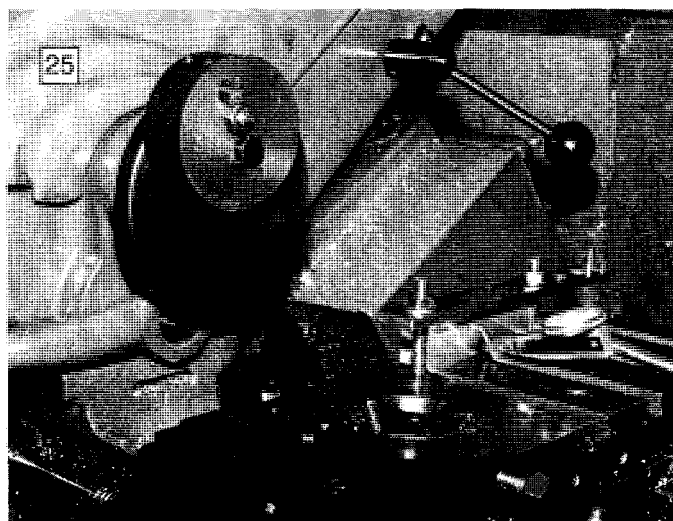
Crankcase material is not so critical. HE30 is the same as 6061 T6 which is the most readily available aircraft grade aluminium alloy in the U.S.A. but any hard, free-cutting aluminium alloy will do. The alloy specified as HE15 is known in the U.S. as Dural and is specified as 2024 T6511.



V8 AERO ENGINE



24: Flycutting a cylinder head block.

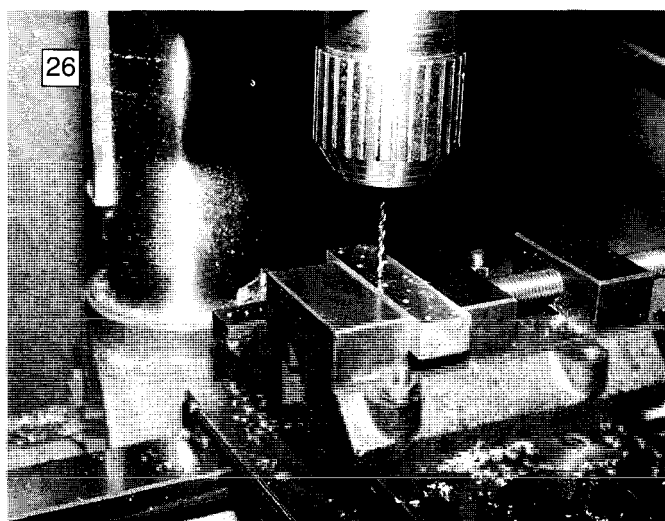


25: Using a lever type DTI to set a cylinder head block true prior to machining the second face.

V8

Fourstroke Aero Engine

Eric Whittle
describes the first stages
of work on the cylinder
heads for his 10.6cc air
cooled aero engine with
glow plug ignition
*Part IX continued from
Page 617
(17 November 1995)*



26: Drilling a combustion chamber face using the vertical milling spindle.

Cylinder Heads.

The cylinder heads for my engine were carved from HE15 aluminium alloy, but HE30 is quite adequate for the job. It's just that I happened to have a piece of rectangular HE15 alloy large enough to make the two heads. This seemed more convenient than machining them from round bar. Whichever you use, first prepare two accurately machined billets, 0.75 x 0.55 x 2.860 inch. My method was to saw to the rough dimensions, hold in the 4-jaw chuck to face to 1/16in. oversize and finish to size by flycutting. **Photo 24** shows this operation in progress.

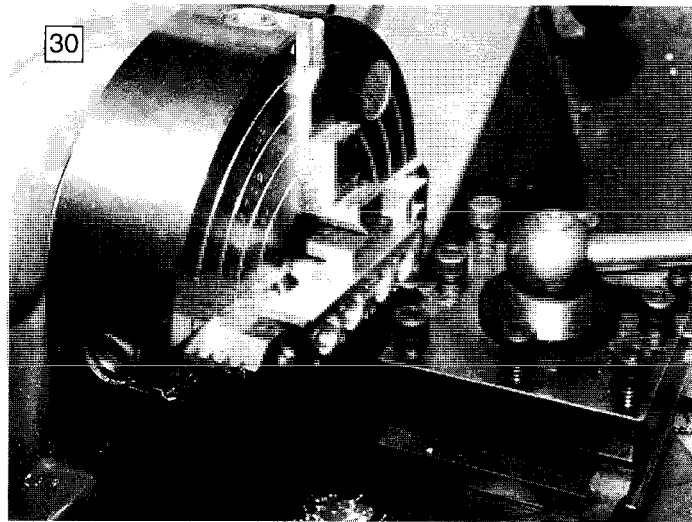
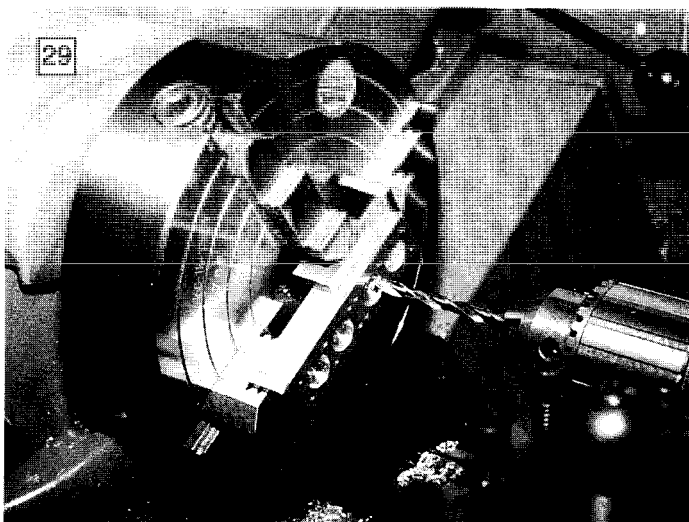
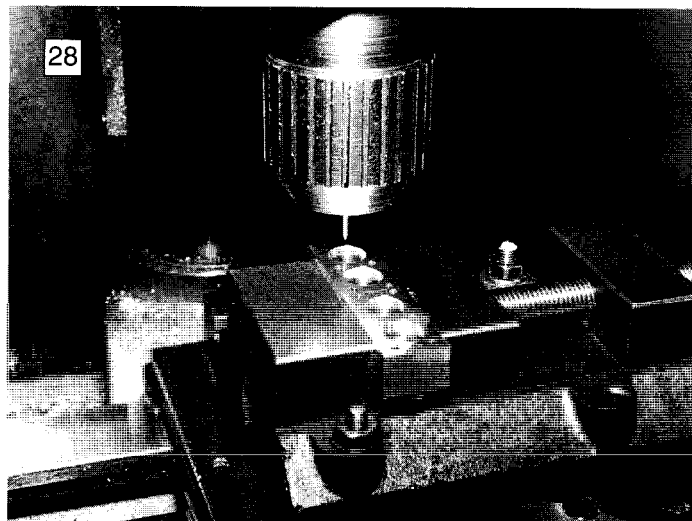
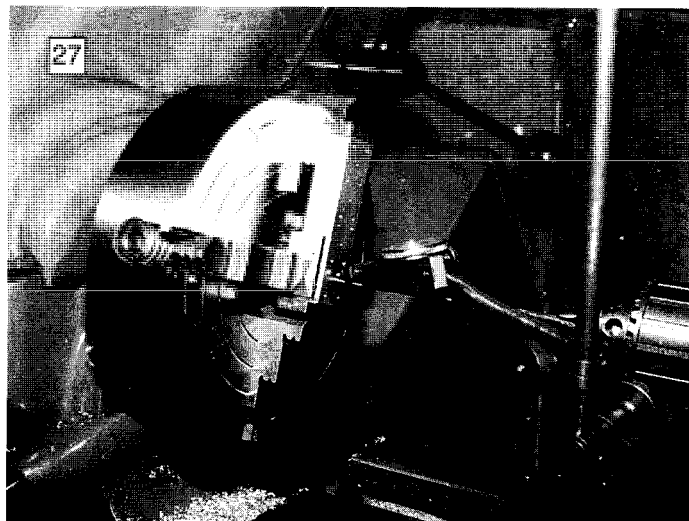
After flycutting the first side, turn the block through 180deg. and set the first machined face dead true using the DTI as shown in **photo 25**. It is important that the block finishes up perfectly parallel, otherwise the fins on the cylinder head will end up tapered.

Considerable time will be saved and there will be a much better chance of ending up with identical cylinder heads if work on both is progressed together through the many operations of their manufacture. A great deal of work is involved in their production so it is essential to thoroughly understand the drawings and not to rush the job. All necessary dimensions are shown on the drawings you may have to look for them but they will be there! Most of the important dimensions will also be referred to in the text.

When the two blocks have been finally machined to size each should be marked out with a faint scribed line along the middle of what you have decided will be the combustion chamber faces. A small centre mark halfway along this line is required to identify the middle of the face. The block is then mounted in the machine vice and the centre mark set under the milling spindle with the 1/8in. dia. centre piece as for the cylinder mounting faces and spigot plates earlier.

Set the work dead true lengthwise and in both horizontal planes then, using the same feed screw readings used to position the 4 cylinder and 12 fixing screw positions, centre drill all 16 places with a 1/8in. centre drill. Go no deeper than 0.050in. with the four cylinder positions. The combustion chambers are only 0.065in. deep and the valve seats are very close to each other in the middle of the chamber roof, so a centre hole at this point would be most unwelcome later on! After centering all 16 positions, drill No. 43 the 12 fixing screw holes (**photo 26**) and bring the second head to the same stage.

The combustion chambers are next bored with the block held in a 4-jaw chuck. Set the work with smooth faced packing pieces to protect the finished



surfaces. Centre the first chamber using the DTI (**photo 27**) then bore the chamber 0.458in. dia. for a depth of 0.065 inch. Use a tool with a tiny radius stoned on the tip. When all 8 chambers have been machined return to the milling set up again to position and centre mark for the valve ports.

With the chamber so small, the valve port positions must be very precisely placed. There is little room for error since there is only some 0.020in. between the valve seat and the chamber wall so, if the work is set as for the previous centre drilling operation and the 1/8in. centre piece fitted to the milling spindle, the centre piece can be positioned in the middle of one of the end chambers using the turning marks to get it dead central. Alternatively, a mild steel plug could be turned to a snug fit in the chambers, a 1/16in. hole drilled in the centre and a disc parted off to a width of about 1/8 inch. This disc could then be placed in the chamber and the milling spindle centred on the 1/16in. hole. Whichever way you choose, try to get it right!

Having found the centre position of one of the end chambers, move the work 0.1145in. toward the end of the workpiece and lower the milling spindle centre point to mark the end valve position. Taking due account of free

play, move back for 0.229in. to mark the next valve position, a further 0.375in. for the third position and 0.229in. for the fourth. A further 0.531in. will position the fifth valve, then 0.229in. for the sixth, 0.375in. again for the seventh and another 0.229in. for the eighth. If you have a pocket calculator, all these dimensions are easily checked from the drawings. **Photo 28** shows the 1/8in. centre being used. Both heads should be brought to this stage before drilling and reaming the ports.

The valve guide holes, ports and seats are all machined at the same setting in the 4-jaw chuck. Set in the chuck as for boring the combustion chambers and set an end valve centre mark true with the DTI. Centre drill and drill for 1/8 inch. Ream right through the head block. I ream by pulling the spindle round by hand using the countershaft V-belt. Open out the port with a 3/16in. dia. drill for a depth of 0.306in. from the combustion chamber face, or 0.240in. from the chamber roof (**photo 29**).

Set the compound slide over to 45deg. and use a small, sharp boring tool mounted in the tool post to turn the valve seat. Set the tool exactly to centre height and with the aid of an eye glass, make sure you can withdraw the

point of the tool from the seat without fouling the wall of the chamber. Owing to a slight out-of-balance, mainly due no doubt to the weight of the chuck jaw, I found it necessary to drop to the second highest ungeared speed when machining the two end ports when using the Myford Super 7. Taking several light cuts, the seat should be turned to a width of about 0.020 inch. Be very careful when applying the cuts and withdrawing the tool-it would be all too easy to cut into the chamber wall and we are aiming to produce perfect heads. This is slow, painstaking work, especially setting up in the 4-jaw for each of the 16 valves. Try to get all the seat widths to look the same, for which the use of an eye glass is helpful. **Photo 30** shows a seat being turned.

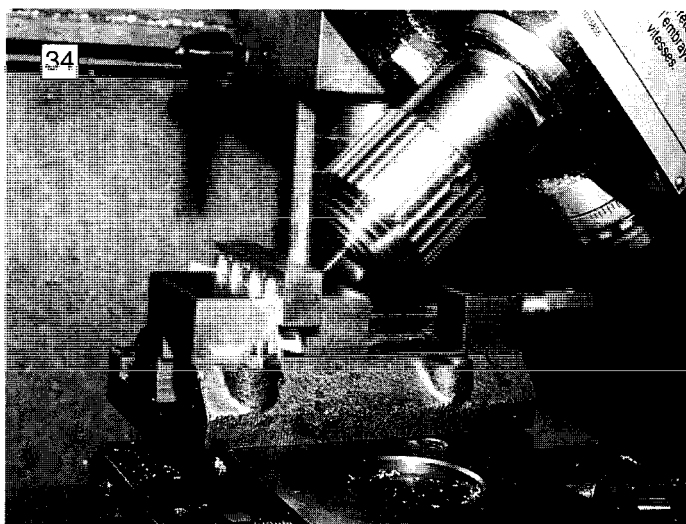
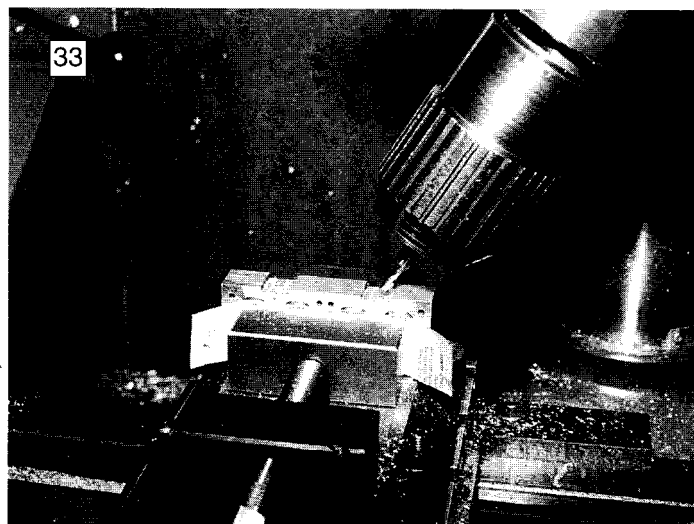
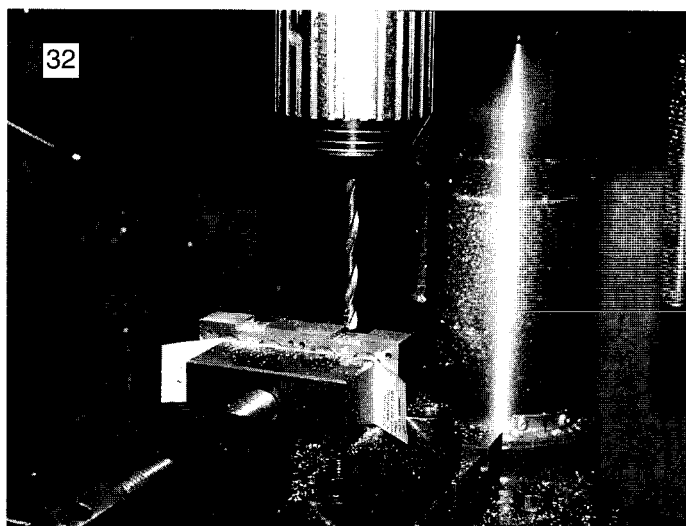
When the remaining 15 ports have been done, a start can be made on milling the head to shape. Mark out the side of the head carefully from the dimensions shown on my drawing. We shall be machining the two areas which will form the induction flange mounting face-the drawing shows them to be placed exactly midway between the end pairs of combustion chambers, or in line with that pair of fixing screws. Mark the areas to be milled with well defined scribed lines across the depth of the block and set in the machine vice

27: Centering a combustion chamber position prior to machining.

28: Centre marking a valve port.

29: Drilling a valve port.

30: Machining a valve seat at 45 degrees.



31: Machining an induction flange seat.

32: Drilling an induction port hole prior to milling and drilling the passageway at 30 degrees.

33: Milling an induction passageway through with 1/8in. slot drill and the vertical milling spindle set at 30 degrees.

34: Setting up a cylinder head for drilling exhaust passageways and milling exhaust stub seat areas

under the milling spindle. Align true lengthwise and horizontally and fit a 1/4in. dia. cutter to mill the induction flange area down to a depth of 0.083in., leaving the milled surface 0.412in. wide. Repeat this operation on the other end of the block. **Photo 31** shows the operation in progress.

While the block is set in the machine vice the two 0.166in. dia. induction holes can be drilled. They need to be positioned exactly between the two combustion chambers, 0.1875in. up from the combustion chamber surface and drilled to a depth of 0.229in. (**photo 32**).

The head of the milling machine will have to be set over to an angle of 30deg. for drilling the passageways through to the ports. Fit a piece of round mild steel of suitable diameter into the milling spindle and adjust matters until it enters the 0.166in. dia. hole. This will ensure that a No. 26 drill will not foul the edges of the hole. When this has been done, replace the setting rod with a 1/8in. dia. slot drill and bore through to the valve port. Replace the milling cutter with a No. 26 drill and drill through to the port. Watch the inside of the port and be careful not to go too far to foul the opposite side. Repeat on the other induction hole and then set the milling head over to 30deg.

in the opposite direction for the other two passage ways. **Photo 33** shows this operation in progress. Bring the other head to the same stage while the set up is available.

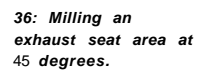
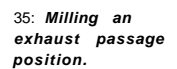
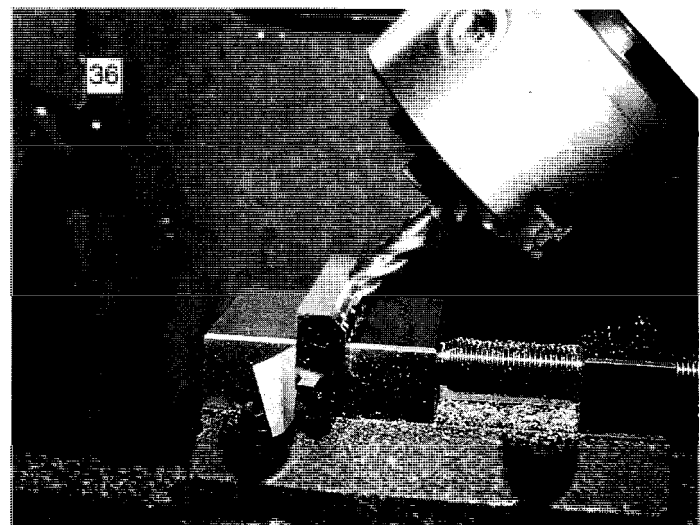
The next job must be to counterbore the 24 fixing screw holes to the depths shown on the drawing. Grind a No. 30 drill to cut a flat bottomed hole. The four holes which pass through the induction port holes should be counter-bored with this drill to a depth of 0.222in. from the top of the block and the other 20 holes counterbored to a depth of 0.384 inch. I did this job on my bench drill using the quill stop to get the depths right. Be very careful to make no mistake on any of the four induction port holes for, even at this stage, the amount of work in the two heads is considerable so study the drawing. Take your time and think carefully about every move before you make it.

The head should now be returned, exhaust side uppermost, to the machine vice under the milling spindle for positioning and drilling the exhaust passageways through to the ports. Lengthwise alignment on this operation is most important as the 45deg. exhaust flange face will also be machined at this setting and any error in block alignment at this stage will

manifest itself in a tapered top fin over the length of the head when the fins come to be machined later. This requirement for accuracy also applies to the horizontal setting. I was pleased to get mine to within 0.0005in. in both planes from end to end of the block.

The milling machine spindle is now set over to 45deg. and the 1/8in. dia. centering pin fitted into the collet. The centre line of the exhaust passage ways coincides exactly with the corner of the block, so touching the point of the centering pin on the corner of the block will put us in the right position for drilling the passage ways, (**photo 34**). Correct positioning of the block is easy looking from the front or the rear—we just have to be careful about positioning the four passageways along the length of the block. They need to be exactly in line with the appropriate exhaust valve port. The drawing shows the end exhaust valve at 1.098in. from the middle of the block lengthwise, putting it 0.330in. from the end of the block. Scribe a small mark at this dimension near the corner of the block, then align the 1/8in. centre piece with the mark to locate the position the first exhaust passageway.

Now fit a 3/16in. dia. cutter and spot face the position to just give a full circular face (**photo 35**), then move the



Machining the exhaust flange face is the next job. Since my Pultra 10mm headstock adapter collets run out at 7.5mm I had to fit a 3-jaw chuck to my milling spindle to hold the 1/2in. cutter required to machine the flange face (photo 36). Mill the face down to produce a side height of exactly 0.3375in. as shown on the drawing. This will give us a half thickness top fin on the completed head and will also just enable the 1/2in. cutter to clean up the face without the problem associated with moving either the work or the cutter. Watch this point as you proceed and adjust the position of the work accordingly. A 5/8in. cutter would make the job slightly easier.

● *To be continued.*



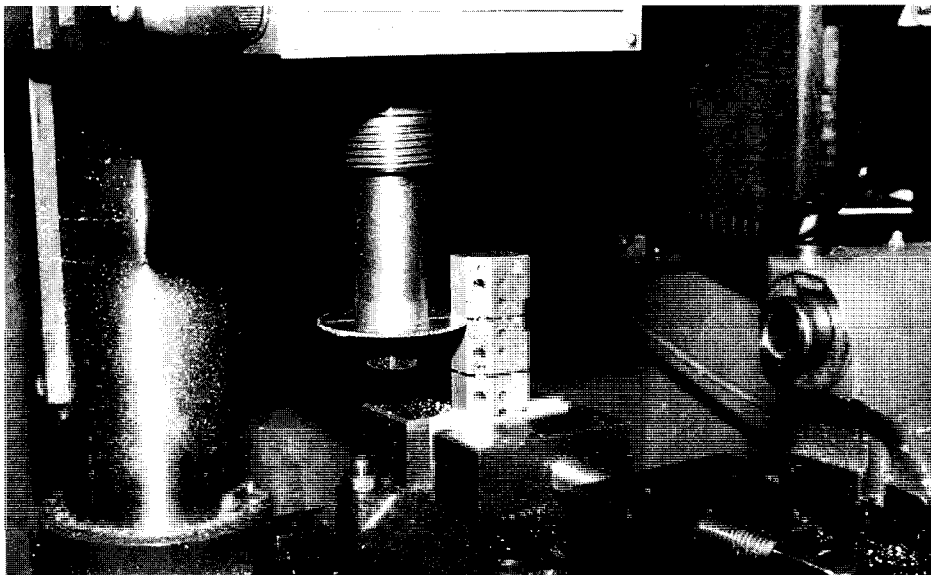
V8

Fourstroke Aero Engine

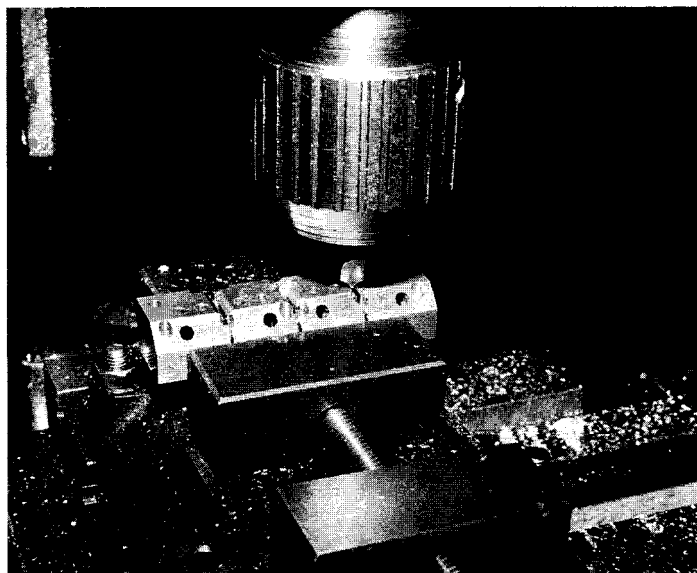
Eric Whittle

describes the operations necessary to finish the cylinder heads.

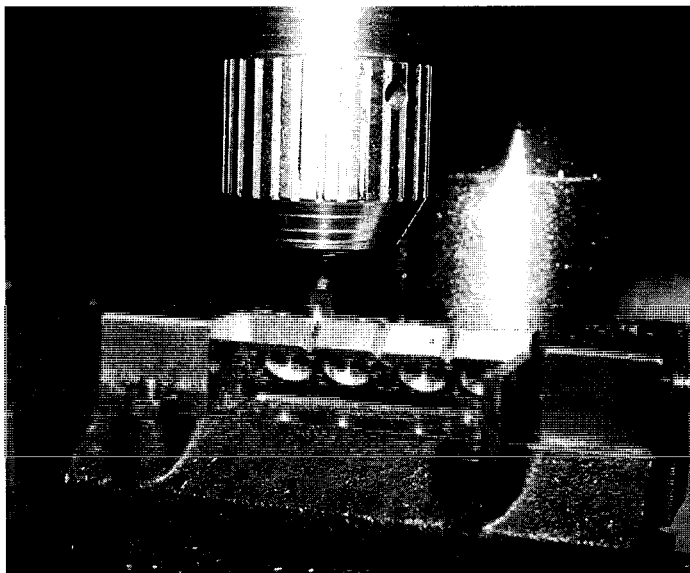
● *Part X continued from page 759*
(15 December 1995)



37: Cylinder head separation is represented by means of 0.040in. slots produced by the use of a suitable slitting saw.



38: After the slots have been cut, their corners are radiused by the use of a D-bit form tool specially prepared for the task.



39: The cylinder head is set over to 45deg. to allow the corner rounding operation to be completed.

Cylinder head slots

The 0.040in. slots which divide the exterior of the head into what appears to be four separate heads can now be cut. My technique is shown in **photo 37**. Use thin card packing to protect the surfaces of the head already machined to a finish, and check to ensure that the arbor on which the saw is mounted does not foul the vice jaws when cutting the middle slots. Align the cylinder head truly vertical in the machine vice and position the saw using the fixing screw holes as a guide. The saw cuts should pass exactly through the middle of the counterbores to a depth of 0.170in. for the three top slots and 0.100in. deep for the four side slots. Reverse the position of the head to machine the remaining slots. Note that slots are not cut in the induction manifold flange faces.

The long edges of the slots may next be radiused. Purely cosmetic maybe, but the finished head looks much better with them than

without. They are quite easy to machine with a home-made silver steel D-bit. The D-bit can be machined to a radius of 0.080in. with a suitable round nosed form tool. The resulting point on the end of the bit is then ground to 1/32in. width. The D-bit is then hardened out and clearance is applied to keep the non-cutting edge off the work. The D-bit is used as shown in **photos 38** and **39**. **Photo 39** shows the slots in the exhaust flange face being radiused. The corners of what will be the banks of fins on the induction side of the head may be machined with the same tool - this will save a great deal of work with needle files later on, after the fins have been cut.

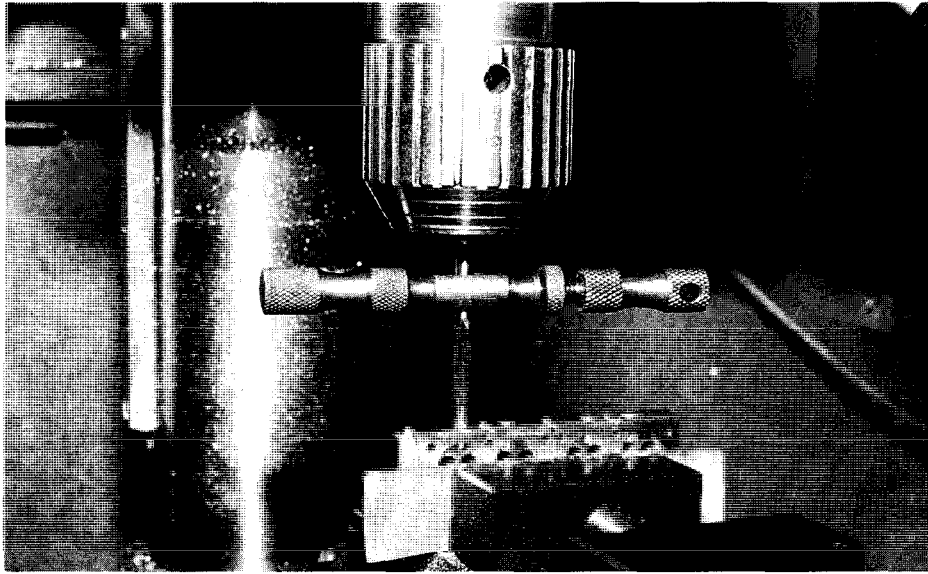
Glow plug holes

The next job is to position, drill and tap the glow plug holes. These should be very accurately positioned vertically from the combustion chamber face. My drawing shows this dimension to be 0.125 inch. The accurate vertical placement

of the glow plug hole will determine not only the position of the glow element relative to the combustion chamber but also the size of the square shaped hole which breaks into the chamber roof, and to some small extent the compression ratio, so the marking of a scribed line 0.125in. above the chamber face needs to be done carefully. Lengthwise placement of the four holes also needs to be right.

Assuming that the chambers and fixing screw holes were correctly positioned in the first place, then the slot positions should also be right. These should be exactly between the combustion chambers. The spacing of the holes from this centre position is 0.240in., as shown on the drawing.

Having marked the vertical position with a scribed line running the length of the cylinder head block, the centre position of each hole can be marked on the line. The cylinder head should then be set in the machine vice and accurately aligned by the use of a DTI on the combustion



40: The glow plug holes are threaded 3/16in. x 40tpi. Tapped by hand these threads are started in the milling machine to ensure squareness.

chamber face. The cylinder head should be positioned in the vice so that the top half of the valve ports are visible above the vice jaws. Protect the chamber surface with thin card. **Photograph 40** shows the set up.

Fit the 1/8in. centering pin to the milling chuck and centre the first position under the milling spindle. Using a 5/32in. dia. slot drill, drill to a depth of 1/4 inch. The cutter will break through the roof of the chamber to form a rectangular shaped hole. The bottom of this hole should be 0.025in. from the induction valve seat-note that this 0.025in. dimension is more important than the 1/4in. depth so watch the progress of the cutter during the operation (I used an eyeglass), and take the cutter down to within the 0.025 inch.

Take note of the feed screw readings, move 0.480in. to the next position and repeat the operations. Since 5/32in. dia. is a suitable tapping size for the thread, a 3/16in.x 40tpi second tap can be inserted into the milling chuck and, with the

assistance of a dab of tapping compound, cut down by hand until the end of the tap is just short of the bottom of the hole. Tap the other hole and move to the other end of the head to repeat the operations on the other two holes, once more noting the feed screw readings. These same readings can now be used to spot face each position with a 1/4in. dia. cutter to a depth of 0.033 inch. The work can then be removed from the vice and the holes tapped to the bottom with a plug tap.

Head screw seal seats

The four recesses for the plastic seals which will seal the long cylinder head fixing screws against induction suction leaks may be machined in next. If the head is set in the 4-jaw chuck as shown in **photo 41**, and the drill previously used to drill for the fixing screws is inserted into the appropriate fixing screw hole, its shank can be set to run dead true using the DTI. Remove the drill and use a small sharp boring tool to cut a

recess 0.140in. dia. by 0.040in. deep. Smooth faced packing pieces must again be used to protect the finished work surfaces.

Rocker perch mounting holes

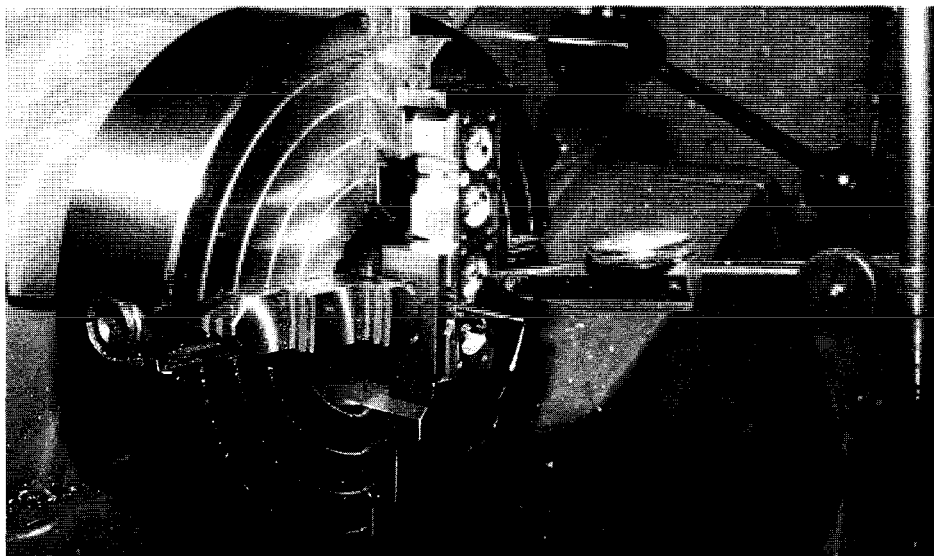
The rocker perch mounting holes should next be positioned, drilled and tapped with four holes per head. These holes are in line with the combustion chambers, set 0.145in. from the centre line of the head towards the induction side and must be positioned accurately to avoid the need for packing washers on the rocker shafts to align the rockers when the valve gear is assembled. Setting them 0.145in. from the centre line is fairly easy, but getting them located on a line which runs exactly halfway between the two valves can be a little awkward and time consuming. Once the four positions have been marked with a centre pop, the cylinder head is set in the milling vice under the milling spindle and each positioned, centre drilled, drilled for 8BA tapping and counterbored with the No.30 flat bottoming drill as were the fixing screw holes previously. Be careful with the depth of the 8BA tapping holes since the bottom of the hole is only about 0.040in. from the combustion chamber roof-see Section D-D on the cylinder head drawing.

Cooling fins

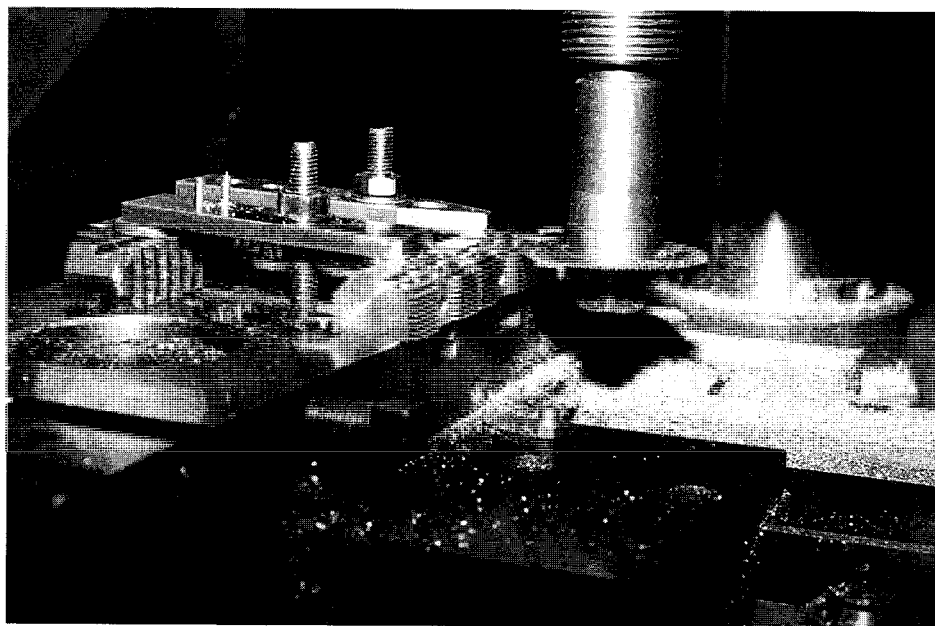
The final machining on the cylinder head is cutting the cooling fins. All are cut with a 0.025in. wide slitting saw mounted in the vertical milling spindle as shown in **photo 42**. The head is clamped directly onto the milling table (or the cross-slide boring table, as in my case). Since no card or paper packing will be placed between the combustion chamber face and the machine table, the table must be perfectly clean and free from dirt and grit. The cylinder head should be aligned true and clamped with about 1/8in. overhanging the edge of the milling table to avoid the saw fouling the table when the bottom side of the bottom fin is being machined.

The drawing shows that eleven fins are to be cut on the induction side of the head and six and a half on the exhaust side. Start with the exhaust side by touching the top of the saw on the bottom of the head i.e. the combustion chamber face, then set the vertical head feed screw to zero and withdraw the saw. Move the saw up 0.325in. to check that it will cut the top groove to leave the top fin 0.0125in. wide. If this looks about right you have set the vertical feed screw correctly and from now on the graduated collar or dial must not be moved until all the fins on that cylinder head have been cut.

Move the cutter back to just below the bottom of the head, return to the zero where the top of the saw just touches the chamber face and move a further 0.025in. to cut or form the bottom face of the bottom fin. Take small cuts at a fine or slow feed with a slow spindle speed on this first cut to avoid flexing the saw and ending up with a tapered bottom fin. I took no more than 0.020in. deep cuts on this bottom operation. Cut to a depth of 0.083 inch. Withdraw the saw and move it up 0.050in., apply a 0.020in. cut for the first fin and groove followed by a 0.010in. cut to finish leaving the groove 0.030in. deep, withdraw the saw and move up another 0.050in. to make the next groove. Continue like this for a



41: Induction seal seats or recesses are bored after setting each hole true with the aid of a DTI on the shank of a suitable drill fitted into the previously drilled hole.



42: Machining the cylinder head fins is a job which repays careful and patient workmanship.

further four grooves when the top fin should be left about half thickness. Be sure not to cut into the spot facings of the glow plug holes as this could cause combustion leaks when the engine is up and running.

Having cut the exhaust side fins, turn the head through 180deg. and clamp it as before to the milling table with 1/8in. of overhang. When aligned true, use the same index readings to machine the eleven fins on the induction side. Here again take only small cuts of about 0.020in. to start each groove after which they can be increased to about 0.040in. to finish the groove to depth. This should prevent the saw from running off over the length of the cut.

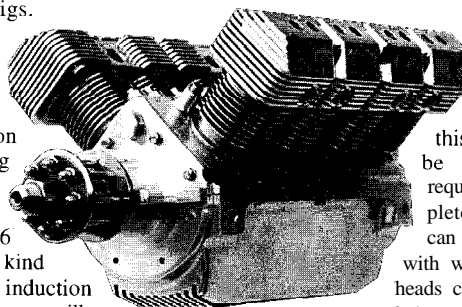
Cut down to about 0.005in. or so clear of the induction flange surfaces remembering that these are gasket faces and must remain untouched. The cuts will be about 0.083in. deep. My drawing shows that the top three grooves must be cut deeper than the seven lower ones—the dimensions are clearly shown. If the dimensions of the block were right to start with, the top fin will be the same thickness as the rest. The three top fins are cut back as shown on the plan view of the cylinder head. The third fin from the top can be cut back to the level of the induction flange face. The second fin can be cut back to almost halfway across the diameters of the six fixing screw holes but keeping clear of the rocker perch mounting holes by about 0.020in. or so. The top fin is cut back to about two thirds of the way across the diameter of the rocker perch holes.

Set the cylinder head to cut the grooves in the ends by rotating it through 90deg. and clamping it down with about 1/8in. overhanging the milling table. Align true once more and make the eleven cuts to a depth of 0.050 inch. Repeat on the other end and then rotate through 45deg. to sink the saw into the corners of the grooves to form the bevels as shown on the plan view. These bevels are required in six grooves on the exhaust side and seven on the induction side, all four corners of the cylinder head being treated similarly.

Cylinder heads—details to finish

Apart now from some rather tedious work with needle files, etc., most of the work on the cylinder heads is now complete. Positioning, drilling and tapping the 16 x 10BA holes for the exhaust flanges must be left until later when the exhaust stubs have been made and can be used as drilling jigs. The 16 induction manifold flange holes can be positioned at this stage. Since they must go between the chamber roofs and the bottoms of the 30deg. angled passageways to the induction valve ports, placing of the bottom holes is critical since there is little spare room. If the 10BA stud hole is drilled and tapped to clear the roof of the chamber by about 0.010in. the thread OD should just show itself in the bottom of the angled induction passageway. The stud will be secured with Loctite so this should be acceptable, the passageway being reamed out with the No. 26 drill afterwards. Whatever happens, don't break through the chamber roof! This is why these bottom holes cannot be left to the rather imprecise positioning resulting from the use of the induction manifold flanges as drilling jigs.

Placing the upper holes is far less critical—the dimensions on the drawing are only a guide and a decision must be made regarding the exact positions. Removal of any thread tops with the No. 26 drill is essential as any kind of obstruction in the induction manifold or passageways will cause mixture flow and throttle control problems later when the engine is run. Since the ends of the studs come very close to the rods and it would be difficult to adjust their lengths once they have been fixed in place, it may be best to leave the final Loctite fitting of the bottom studs until the valve gear has been made and the push rods are in place



43: Progress to date., Builders who have reached this stage should be well pleased with their efforts.

The exhaust stub pipes can now be made and fitted to finish off all the work on the heads. When made, they can be used as a drilling jig to position the 10BA stud holes in the cylinder head. A piece of mild steel turned to a good fit in both the exhaust passage way and the exhaust pipe can be used to locate the flange on the cylinder head at the correct angle of 30 degrees. The stud holes may be drilled using the bench drill and supporting the cylinder head at the correct angle of 45deg. in a Vee-block. The angles alternate from one flange to the next, as the drawing shows, so close attention should be paid to avoid mistakes!

The head fins are rounded off to the dimensions shown in the plan view. To work on the ends of the three top fins, I ground the edge of a flat needle file smooth and then polished it on fine emery cloth so that it could be used on one fin without risk of damage to the fin below. This is one of the tedious jobs to be tolerated in this game of miniature I.C. engine construction. The four corners of the head are much easier, a second cut file in one hand and the head in the other soon gets the job done—after filing to shape and radius, rub them on a sheet of 1200 wet or dry on the surface plate to finish.

Cylinder head bolts

The 24 head fixing screws are probably the most logical items to make next. I made mine from silver steel, mainly because I couldn't obtain any grade of high tensile steel in the smaller diameters and making them from cap head Allen screws seemed both wasteful and expensive. The silver steel screws have so far proved to be quite good enough. To date they have been in and out many times before, during and after the running of the engine when initial problems were being dealt with. The heads were hardened and tempered to preserve the screw-driver slots.

A fairly straightforward job, they are turned with a round nosed tool capable of both left and right hand cutting. The tool should be dead sharp and set exactly to centre height. Start with a length of 1/8in. dia. silver steel, turn and thread 8BA for 3/16in. then drill with a 1/8in. dia. centre drill to support the work with the back centre during turning. The threads should be a shake free fit in the 8BA crank

case holes, so set the die for the correct fit at the outset. This is another of the less exciting jobs on this engine. With 24 studs to be made, some patience is required. When they are completed the 0.070in. diameter: can be polished at high speed with worn emery and the cylinder heads can be assembled to the rest of the engine complete with the rubber rings and spigot plates to check that the 0.070in. dia. sections of the studs all end up exactly between the spigot plate and the cylinder mounting faces. It is important that all the lengths and positions look identical. Check that the thread length is not too long and fouling any part of the crankshaft. **Photo 43** shows the progress to date.

● To be continued.



Fourstroke Aero Engine

Eric Whittle

begins his description of work on
the valve gear components.

Part XI continued from page 92
(19 January 1996)

Work on the valve gear is a long slow job calling for considerable patience. Most of the work is fairly straightforward—the rockers are probably the most tedious part, but these will mainly be machined using jigs on a production basis to make the job as easy as possible and maintain uniformity of the finished items.

Valve guides

We need to start by making the 16 valve guides. A simple turning, drilling and reaming job in phosphor bronze, these are shown in the upper drawing (M.E. page 759 15 December 1995). The only point to watch is that the press fit OD must be turned at the same chuck or col-

let setting as the drilling and reaming. The first 0.100in. of the 1/8in. dia. should be polished down to 0.124in. to ensure true vertical alignment when the guide is installed in the head prior to pressing home which can be done on the bench drill using a touch of Loctite 603. After being pressed into place, each guide should be reamed through again by hand.

Valves

The valves, of which there are 16, are made from stainless steel which is heat treated prior to final machining to prevent distortion and ensure perfectly concentric valves. In the past I had experienced a great deal of trouble trying to turn truly concentric valves in stainless steel. No matter how careful I was or how small the final cuts on the stems, the valve always ended up eccentric to some degree. I finally decided that the problem was caused by relief of internal stresses during machining. By turning to about 0.010in. oversize, heating to bright red and allowing the valves to cool in still air (normalising) the problem was solved and perfectly concentric stems resulted.

Start with a length of 1/4in. dia. stainless steel. Hold with 1.250in. protruding from the chuck jaws or collet, whichever you are using, and reduce to 0.206in. dia. for 0.800 inch. Now turn down to 0.150in. dia. for 0.650in., then reduce the first 1/8in. to 0.110in. dia., the second 1/8in. to 0.120in. dia., the third to 0.130in. dia. and the fourth to 0.140in. diameter. Remove the work from the lathe, normalise as described above, return to the lathe and reduce the first 1/8in. to 0.0940in. dia., the second to 0.110in. dia., the third to 0.120in. dia. and the fourth to 0.130in. diameter. Reduce the second 1/8in. to 0.0940in. and take a further 0.010in. from the third and fourth steps. You will observe that we are trying

to turn the stem to size stage by stage while keeping the cutting forces as small as possible. When the entire stem is down to 0.094in. dia., the 0.070in. dia. reduced part of the stem under the valve head is carefully cut using a sharp round nosed tool with a 0.0625in. nose radius. The valve seat can be turned by setting the compound slide over to 45deg., the same round nosed tool can be used to turn the seat.

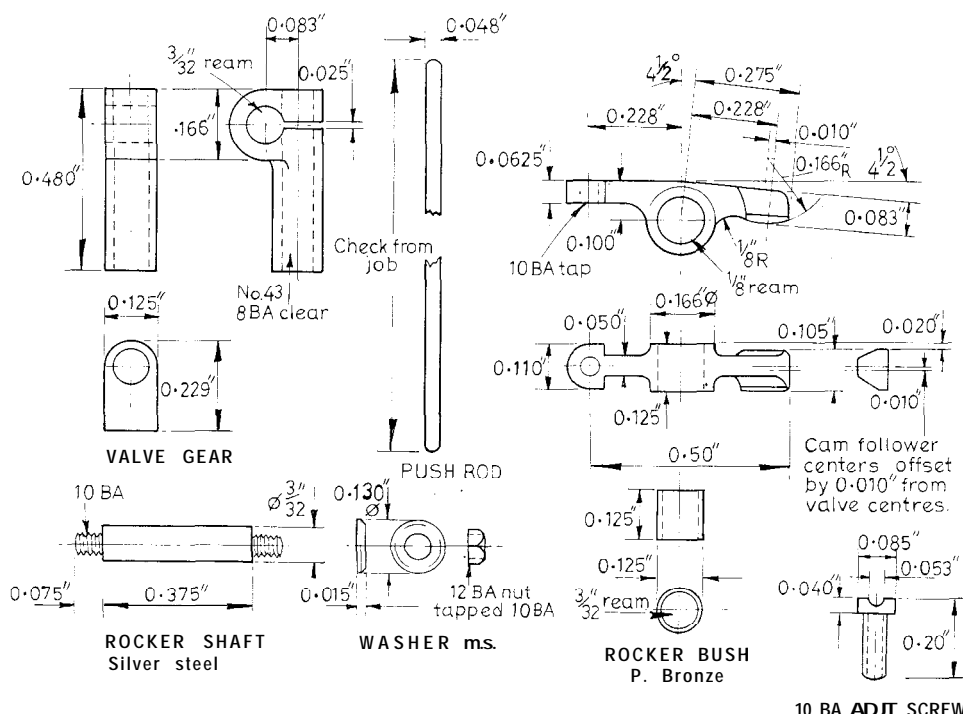
The final job at this chuck setting is to polish the stem to a slide fit in the valve guide. Do this in the usual way with 800 grit wet-or-dry paper backed with a 6in. steel rule. The valve stem should be overlength by about 1/32in. at this stage. Part off 0.020in. overlength and bring all 16 valves to this same stage. You may well find that the valves will not be interchangeable tits with the bronze guides. Some may, some may not, so it is probably best to keep each valve in its own guide once it has been fitted.

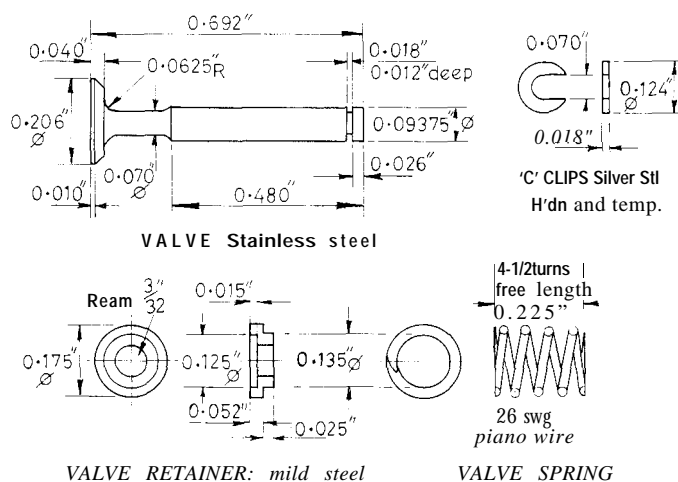
Face each valve to length—start by facing the heads to the dimensions shown then face the stems to an overall dimension of 0.692 inch. I happen to have a set of collets which allows the head to enter the collet body so enabling me to hold the stem perfectly true for machining the circlip groove, but I still have to remove the collet to use the micrometer for checking the overall dimension when facing to length.

When all the stems have been turned to length, the circlip grooves can be cut with a 0.020in. wide parting tool to a depth of 0.012in. and the sharp corners removed from the edges of the groove. Bring the remaining 15 valves up to the same stage.

Springs

The springs are made from 26swg piano wire. You may have to experiment with the diameter of





the winding mandrel to achieve the correct internal diameter for the spring which should be an exact fit on the top diameter of the valve guide. Make them according to the drawing and grind the ends square with the length. If suitable commercial springs can be obtained so much the better, since not only will these be much less trouble, they will be correctly heat treated-although my piano wire springs seem to do the job and have given no trouble to date.

Valve retainers

The valve retainers are easy to make from mild steel. Start with a length of 3/16in. dia. mild steel and reduce 1/2in. to 0.175in. diameter. Drill and ream 3/32in. dia. for 1/2in., turn to the spring inside diameter for 0.025in. then part off for an overall length of 0.052 inch. Produce 16 pieces to this stage. Fit a collet to hold the 0.025in. register of spring i/d and fit a 1/8in. dia. end mill in the tail-stock chuck to cut the 0.015in. deep recess for the valve stem circlip. Bring all 16 valve retainers to the same stage.

Circlips

The circlips are the next job-the smallest items on the engine, they aren't too difficult to make. After first trying to make them using Swiss files, etc. and getting nowhere fast. I found that exasperation and despair can be the mother of invention. The method to be described was the answer to the problem. A piece Of 3/16in. dia. silver steel is turned to 0.124in. dia. for 1/2in., centre drilled and drilled 0.070in. dia. for 1/2 inch. A parting tool is ground to 0.070in. wide and mounted on its side in the four-way tool post and the blade set at dead centre height. The parting tool can now be used to shape a slot along the workpiece through to the hole by the use of saddle movement. This will provide us with a stock length of circlip, all we need do is part them off with a 0.015in. wide parting tool-in fact, the parting tool is more of a pain to make than the circlips! Part them off to a width of 0.022in. which will allow for rubbing down to size to fit the valve stem grooves. Make 20 clips to this stage.

Rub down each clip until it will enter into the valve stem groove, then clean the clip and groove and fit a retainer to the valve. Check that the clip will go into the retainer recess when installed in the groove. The clips must now be hardened and tempered. I did this by holding the clip on a piece of thin sheet steel in the propane flame to red heat, tipping it into a jug of water. fishing it out with a magnet and polishing it with 1200 wet or

dry on the surface plate. A very low flame and the same piece of sheet steel were used to temper to light straw before being quickly tipped into the water again. Retainers and clips are best identified with their individual valves by finally installing each valve into the head as the circlips are heat treated. There is no need to use any sort of abrasive on the valve seats to grind them in as the super fine finishes of the turned seats will be better than any sort of ground in surfaces-the first few minutes of running will produce completely gas tight valves

To fit the valve with the spring and circlip etc, thoroughly clean both valve and seat with tissues, insert the valve with oil and hold in place with the left hand index finger in the combustion chamber. Fit a spring and retainer, compressing the spring with the left hand thumb nail on the retainer. Grip the circlip with a small pair of good quality flat nosed pliers, insert it into the stem groove and ensure that the clip seats into the recess in the retainer. You will need to stick the circlip onto the jaws of the flat nosed pliers first, using some thick tacky grease. Carefully lay the pliers on the bench while you tit the valve and spring, etc. Press down with your left hand thumb nail to reveal the stem groove. you can then just pick the pliers up and insert the clip in the groove.

Rocker perches

The 8 rocker perches or brackets are the next items to be tackled. These are made from 1/4in. x 1/8in. mild steel strip, a length of which is set in the 4-jaw chuck and positioned to enable the stem of the perch to be turned offset as far as possible to one side of the 1/4in. dimension. It is turned with a 1/16in. radius round nosed tool to 1/8in. dia. for 0.320in., centre drilled and drilled No. 43 for 0.525in., then parted off to an overall length of 0.500 inch. Some careful adjustment of the chuck jaws will be needed in this operation to position the 1/8in. dia. of the rocker stem in the middle of the 1/8in. thickness of the steel strip. Make a further 7 pieces to this stage.

Drilling and reaming the 3/32in. dia. holes for the rocker shafts is next done by carefully marking each one with an accurately positioned centre pop mark. A simple holding device is required to hold the work firmly on the drilling machine table for the drilling and reaming. A piece of 1/8in. thick plate about 2in. square was drilled and tapped 6BA to take two holding down clips to secure the workpiece flat and firm on the plate which is then held down by hand. Ensure that the ends of the 6BA screws do not project

below the plate when the workpiece is tight. The centre pop marks can now be drilled 1/16in. dia. through, followed by a No. 31 drill and 1/8in. dia. reamer. Clamping the work to the jig plate ensures that the holes will be square to the stems. When the first hole has been drilled and reamed through both work piece and plate, open out the hole in the plate hole to 1/8in. dia. to clear the drill and reamer on the 7 subsequent perches.

When all eight perches have been drilled and reamed set them up one at a time on the rotary table to machine the profile around the 3/32in. dia. reamed hole using a 1/8in. dia. end mill. Face each perch to length by holding the stem in a collet. The 0.025in. saw cut is put in by holding the perch by the half round boss in the machine vice mounted on a vertical slide and the slitting saw in the lathe mandrel.

The height of the rocker shaft centres should be 0.175in. above the top of the cylinder head. so if the perch mounting holes were counter-bored to the 0.222in. depth shown on the drawing, the perch stems must be faced to be 0.397in. from the rocker shaft centres. Since the counter-borings may differ by a thou or two from perch to perch, it is best to get the first one right then face each of the others to suit. Use a slightly tapered silver steel mandrel on which to push each perch for the facing operation and take very light cuts. Keep the mandrel as short as possible. A piece of 3/32in. dia. silver steel threaded through from one perch to the next will be a good guide to getting them all the same height. They are secured into position with 8BA studs and 10BA nuts tapped out to 8BA. The 8BA studs should be waisted with a round nosed tool at the height of the rocker shaft to allow the shaft to be inserted through the perch boss. If a small flat is filed on the stud above the shaft and in line with it, the perch can then be removed complete with the shaft, otherwise the shaft must be removed before the perch can be lifted from the 8BA stud.

Rocker shafts

If you make the rocker shafts next, you will have somewhere to put the rockers as they come off the production line. My drawing reveals that they are simple items, adjustment of the length of the 3/32in. dia. plain section is the only thing to watch-make them 0.010in. overlength to start with and adjust each one later to its own pair of rockers. Make and fit the nuts and washers, the washers from mild steel and the nuts from 12BA nuts drilled and tapped out 10BA.

**To be continued.*

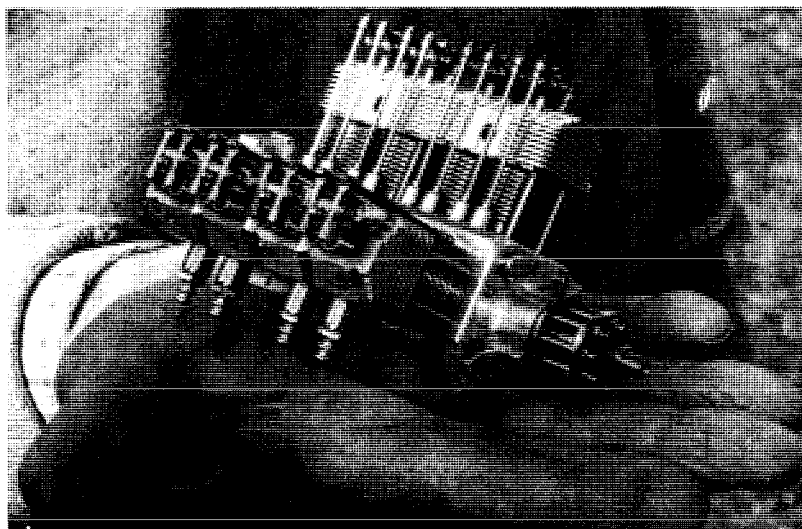
V8

Fourstroke Aero Engine

Eric Whittle

finishes the valve gear and describes the final assembly routine for his handsome little award winner.

● Part XII continued from page 219
(16 February 1996)



Just like that!

Rockers

The rockers are made from the same 1/4 x 1/8in. section strip steel as used for the perches. Start by cutting 16 pieces 5/8in. long. Carefully mark and centre pop each piece exactly in the middle and 0.100in. from one edge for the 1/8in. dia. reamed hole which houses the bronze bush. Drill and ream as for the perch bosses using the same holding down plate-the 6BA screws may have to be re-positioned. This method will ensure that on final assembly the holes will be truly square with the rocker shaft.

When all 16 pieces have been drilled and reamed, the 4.5deg. angle can be machined in the top of the workpiece. This is probably best done by making a plate from 1/16in. steel of length and height depending on the size of your machine vice jaws. One edge of the plate is milled to an angle of 4.5 degrees. It can then be placed in the machine vice, the workpiece placed on top of it and pressed down while the vice is tightened. This should provide 16 identically machined angles.

The next job is profiling the the rockers in plan. A facing or recessing job, this can be done with a round nosed tool by mounting the workpiece on a tapered 1/8in. dia. mandrel, much like the recessing of the large camshaft gear. Recess to a depth of 0.0375in. each side of the workpiece to the proportions shown on the drawing. Machine the bosses to 0.166in. diameter. The curved working face at the valve end of the rocker should finish about 0.120in. long.

When all 16 pieces have been brought to the same stage, mill the sides to profile with a 1/8in. dia. cutter. A rotary table is convenient for this for which a centre spigot will be required to hold the workpiece by its 1/8in. dia. reamed boss hole. The 1/8in. dia. section of the spigot which fits the workpiece should be threaded 1/8in. x 40tpi to secure the rocker to the spigot. The spigot should be a tight fit in the rotary table to ensure that the work does not rotate during the milling operation.

When all 16 rockers have been profiled, excess metal can be sawn from both the front and tail ends. Reduce the tails to a thickness of 1/16in. by inverting the rocker in the machine vice

with the tail overhanging the end of the vice jaws. Be sure to set another rocker (or suitable packing) in the other end of the vice jaws to keep them parallel when the vice is tightened. When the tails have been taken to size it is probably best to machine each rocker to final length. I returned mine to the spigot on the rotary table and milled them to length with the flank of a 1/4in. dia. cutter. It is prudent to arrange a stop of some sort on the rotary table to prevent the work from rotating due to the cutting forces. This stop will also ensure that each piece is identically and squarely machined to length. Nose and tail ends should both be given the same treatment.

My drawing shows the valve end working face of the rocker to be curved to a radius of 0.166 inch. The location of the centre of the circle for this radius is shown and a fixture will be required for the rotary milling. I made a 1-1/2in. square plate from 1/8in. thick steel into the centre of which was Loctited a 1/8in. dia. silver steel peg with a short length of 1/8in. x 40tpi thread. The rocker was secured with a suitable nut and washer. A 1/16in. dia. peg was then fixed into the plate under the tail end of the rocker to act as a stop against rotation under the forces of cutting. The centre position for the radius was then carefully marked out and centre popped into the plate.

If you follow my example, mount the rotary table on the milling table and centre it under the milling spindle. Secure the plate to the rotary table with the centre pop mark also centred exactly under the milling spindle. Set the feed screw dial to zero and move the work 0.228in. (the 0.166in. radius plus the radius of a 1/8in. cutter). Fit a 1/8in. dia. end mill into the milling spindle and machine the working face of the rocker. Be sure to arrange things so that the cutting forces press the rocker against the stop peg. An alternative to the stop peg under the tail of the rocker is a stop on top of the front end. This would produce identical depths of the front ends of the rockers. Such a stop could be a piece of flat steel strip clamped to the rotary table and adjusted to position relative to the rocker. The *modus operandi* will depend to some extent on the size of the available rotary table.

Next drill and tap the 10BA adjusting screw

holes in the tail ends. It is probably best to make and use another jig for this. A 2in. length of 3/4in. square steel is drilled and reamed for 1/8in. and 1/16in. silver steel pegs similar to the plate jig used previously. The rocker is then mounted on the two pegs with the tail of the rocker being supported by the 1/16in. dia. peg. The steel fixture is then held in a machine vice with the top surface of the rocker uppermost, i.e. with rocker the right way up and tail end parallel to the drill table. Mark the position of the 10BA hole in the tail of the rocker and make a clear centre pop in the middle of the width. Set the machine vice complete with fixture and rocker onto the bench drill table and secure it with the centre mark truly under the drill spindle. Centre drill the first rocker with a 1/8in. centre drill-use only the pilot point of the centre drill in this operation. Remove the rocker and repeat for the other 15. By this means all the 10BA holes will be identically spaced from the rocker shafts.

Each tail can now be drilled through 10BA tapping size by holding the rocker in the machine vice in the normal way. Tap all the holes with a second tap and round off the tail end with files and emery. It could be set up on the rotary table and the profile milled. I preferred the rotary table approach, after all the rockers are a whole lot of trouble so a little more makes hardly any difference-the valve gear is about the most prominent part of a model four-stroke engine and the first thing the average observer looks at.

Whether you leave the tail end as it is or square it off as shown in the plan view on my drawing is a matter of individual preference. I left mine with the radius created by the round nosed recessing tool; those for my previous Cirrus engines were squared off as shown.

General cleaning up of the rocker front ends will just about finish one of the most tedious and patience-trying jobs on the whole engine. Rounding of the top front corners can be done by filing but here too I went to the trouble of fixing them to the same jig plate on which the valve end working faces were radiused and milled them in a similar way. The front ends can then be cut to an angle of 15deg. as shown by holding

the rocker on the threaded 1/8in. rotary table centre spigot secured in the machine vice under the vertical head. The head can then be set over to 15deg. and all 16 rockers carefully end milled. Make sure that the rocker is properly secure to prevent it from turning under the cutting force. Take small cuts and arrange matters to push the work away from the cutter so that if it does turn nothing too catastrophic will occur.

When all 16 rockers have been treated in this way, 8 of them can be cut back by 0.020in. on the right hand side of the front end and the other 8 cut back on the left hand side to allow for the 0.020in. difference between the valve centres and the cam follower centres. This is so that the rockers are handed left and right for exhaust and inlet. All 16 rockers can now be cleaned up with a rotary wire brush running at high speed in the drilling machine to remove all sharp corners and burrs. Time and trouble should be spent polishing as many of the surfaces as possible with wet or dry paper. The rockers will be chemically blacked later and the better the finish now the better the blacking effect will look later.

The next job is making and fitting the phosphor bronze rocker bushes but before these are fitted, the valve end of the rockers must be case hardened. It is only the bit that works on the end of the valve which needs the treatment so try to keep the Kasenit compound away from the boss area which should retain some ductility so as not to split when the bushes are pressed into place. Insert the bushes on the drill press with a touch of Loctite 603 and re-ream each one by hand. Assemble the rockers to the cylinder head and set each rocker shaft individually to length to its rocker pair.

The 10BA adjusting screws can be made from commercial cheese head screws to the sizes shown and treated with the dental burr to a depth of 0.050 inch. 10BA lock nuts are made from 12BA nuts tapped out to 10BA as previously described.

The 16 piano wire push rods will complete the valve gear, but determination of their lengths must be left until the engine is finally assembled. Metre lengths of 0.048in. dia. or 18swg piano wire are obtainable from any good model shop. Each rod will have to be made to place and the ends rounded in the lathe (at high speed) using a Swiss file and finishing to a polish with fine emery.

Final assembly

The engine should be finally assembled after the cylinders and valve gear, including rocker perches, rockers and push rods have been chemically blacked. I left all the nuts and washers bright. Blacking is a matter of individual taste but there is probably some advantage in treating the cylinders which will then dissipate heat a little better than if they were left bright.

Several chemical blacking agents are available but I used Koldblak as supplied by A.J. Reeves of Birmingham. Easy to use, it produces a good finish on the part when wiped with oil after washing. Components to be treated must be perfectly clean-scrub them thoroughly in hot water with washing up liquid, then rinse them in cold water before putting them into the blacking solution. Take care when blacking the valve gear since each pair of rockers and push rods must be kept identified with their appropriate cylinder.

The cylinders are best done first. They can then be assembled with the heads before fitting the valve gear. Unsure of the chemical effect of the blacking solution, I chose not to black the cylinder bores. Two pieces of the 1/4in. thick ex-conveyor belt sheet rubber (as previously used when sizing the piston rings) were cut and a sandwich made of the two pieces and the cylinder. The assembly was clamped up with a toolmaker's clamp so that the blacking solution was unable to enter the cylinder bore. An incidental advantage of this method is that the piston need not be removed from the cylinder during blacking. The cylinder is lifted from the piston until the gudgeon pin is just revealed when it can be pushed out with a matchstick. The cylinder and piston are lifted away and the pin returned before the piston is slid back into the bore. Make up the sandwich as described, scrub the outside of the cylinder clean and place into the solution. Be sure to tighten the clamp securely since it is this pressure which keeps the solution out of the cylinder bore. The jaws of the toolmaker's clamp will be well blacked by the time all eight cylinders have been treated!

When the chemical blacking is to your satisfaction, assemble the engine complete with the valve gear, check the gear for correct firing order. Check that there is a thou or two of valve clearance and for free operation of all the rockers.

It will be necessary to make and fit suitable gaskets between cylinder heads and cylinders. I

made mine from 0.005in. aluminium litho plate which happened to be coated on one side with an adhesive enabling me to stack 10 pieces together to form one piece of about 0.060in. thick. I stuck this to a smooth faced mandrel to turn and bore to size using a very sharp tool and taking many light cuts. This method produced nice clean burr-free gaskets, essential for this particular application. After machining, the stack was soaked for an hour or two in a suitable solvent and individual gaskets carefully separated with the aid of tweezers. When apart, the gaskets were washed again in the solvent and wiped clean with tissues.

Assembly of the heads to the rest of the engine is fairly straightforward. Eight rubber rings, eight aluminium gaskets and four small plastic seals are needed, the latter to seal against manifold suction leaks at the four long fixing screws which locate through the induction holes in the heads. These seals can be made from small bore fuel tubing cut into 0.050in. slices with a modelling knife or razor blade by sliding a 1/2in. length onto a suitable mandrel which is run at high speed in the lathe.

Thoroughly clean four of the cylinder mounting flanges and the cylinder mounting faces, assemble the cylinders onto the cylinder mounting faces and put the four rubber rings onto the top fins. Fit a spigot plate then stick four aluminium gaskets to the tops of the cylinders with thick grease to keep them in place. This shouldn't be much of a problem as the tops of the cylinders will be below the surface of the spigot plate and accurate location of the gaskets will be easy. Fit the two long fixing screws to the head and thread the two plastic seals onto the screws, pushing them into their recesses. Fit one of the central pair of screws into the other side of the head then, without disturbing the spigot plate, thread the three screws through the plate and carefully lower the head down to the cylinders. Screw the three fixing screws home with moderate torque, keeping the head pressed down onto the tops of the cylinders. Fit the remaining nine screws and tighten down evenly, working from the middle outwards. Only apply torque appropriate to the 8BA threads. The long screws will be sealed by the small plastic ring at the bottom of the induction hole while tightening of the screw head into the counter bored hole will seal the top. Assemble the other head, assemble the valve gear and adjust the lengths of the push rods to their individual rockers. *To, be continued

CAN YOU HELP?

Enquiries for this section are welcomed. Please give as full a description as possible. If a photograph or drawing would assist others, please include one with your request. Replies by letter, please addressed to the M.E. Editorial Office for forwarding to the querist whose full postal address is not normally published.

Although I may be better known as a writer on and historian of tethered hydro racing, 1908 to date, through my regular column in *Model Boats* plus the occasional update in M.E. I would like to know if any of your readers could help me with another project, namely the history and development of tethered car racing from 1939

through its peak in the early 1950s to its popular demise a few years later.

The information I seek is that which has not been previously published, including original photos and company advertising matter. Photocopied material is quite acceptable. To date, I have a full set of *Model Curs* magazines 1946-50, both the hardback books by

Deason & Wright, *Model Mechnic/Model Maker* magazines of the period along with copies of *Model Engineer*. However, I only have a few copies of *Model Cur News* to refer to.

Owing to the short time that tethered cars were raced, I intend for my book go into some detail, so I would be pleased to hear from M.E. readers who can

help in any way. All letters will be answered, and I am happy to reply to any queries which may arise regarding tethered hydro-planes.

Peter Hill
Souldrop, Bedfordshire.

2 I have recently bought a S/H Elliot 10-M shaping machine and

require a copy of the manufacturer's handbook. I would also like to obtain a copy of Ian Bradley's book *Tools for the Lathe and Shaping Machine*.

If any reader(s) could assist me with the above, would be most grateful and would, of course, reimburse expenses.

N. Huddleston
Lancaster, Lancashire.

Fourstroke Aero Engine

Eric Whittle

continues his account of building this elegant miniature with notes on modifying commercial glow plugs to suit and fabricating the inlet manifolds.

** Part XIII continued from page 329
(15 March 1996)*

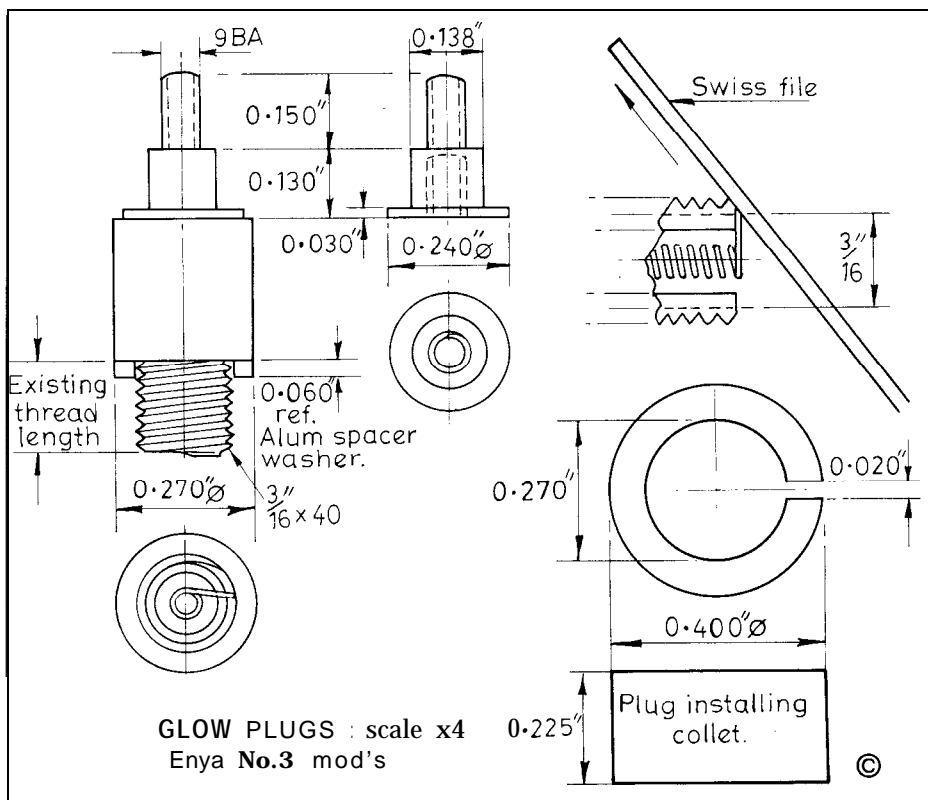
Glow Plugs

Ordinary Enya 3 glow plugs should be available from any good model shop. I settled on these after experimenting with five different makes to find the most suitable for machining to the smallest size. Unfortunately we will need eight of them. At the time of writing they cost about £4 each, so some £32 worth of plugs will be required for this job! However, the modifications are straightforward and fairly easy, so hopefully no more than eight will be necessary.

Begin by making a 3/16in. x 40tpi thread gauge from a piece of the same material from which the heads were made. Use the same tap for the gauge thread that was used to tap the holes in the heads. Hold the plug by its 1/4in. dia. thread in a collet and carefully remove the top screw fitting. Be sure not to lose the mica insulating washer from the centre connector. Reduce the body to 0.270in. diameter. Reverse the work and hold by the 0.270in. dia. in a collet to reduce the 1/4in. dia. thread to 3/16in. dia. up to the existing shoulder.

On examination with an eye glass, you may find that as 3/16in. dia. is approached, the tool gets rather close to the end of the glow element weld. If it is obvious that turning to 3/16in. dia. will touch or cut into the weld you must resort to filing the weld to bring it within the 3/16in. diameter. For this, first position the headstock to bring the weld to 3 o'clock as seen from the tailstock end of the lathe then, with a fine needle file held at an angle of 45deg, remove just sufficient from the weld to ensure that 3/16in. dia. can be obtained without touching or disturbing it. Be sure only to allow the file to cut on the forward stroke thereby pressing the weld into the annular face at the end of the plug, and **not** on the back stroke which would tend to pull the weld away from this face and may cause it to break. My drawing should give a good idea of what you are trying to achieve.

Having reduced the diameter to 3/16in., screw cut the 3/16in. thread to a snug finger tight fit in the thread gauge. Aim for a shake-free fit. To ensure



that the screwcutting tool does not touch and break the weld from the annular face, the tool should begin to cut into the face 180deg. from the weld. This will enable the thread to be cut to its full depth without disturbing the weld. Machine each plug separately, i.e. not on a production line basis!

Screw tops can next be made as shown in the drawing. The centre connector thread is metric but, since I have no metric taps or dies I was pleased to find that 9BA seemed to be an exact fit on the centre brass screw. I therefore made both male and female threads 9BA. These new plug tops are much neater than the larger, rather bulbous looking Enya fittings and are worth the extra trouble involved. Fit the tops to the plugs with a touch of Loctite 603 and don't forget to refit the mica washers.

Make eight aluminium plug washers to the dimensions shown and screw the plugs into the heads. Use a split collet as shown in the drawing, in conjunction with a pair of long nosed pliers, to tighten them down. The glow element should finish at about 1/16in. from the end of the plug hole, so size your aluminium washers accordingly.

It was at this stage that I first ran my own engine. I fitted a 12in. x 6in. propeller and put a small pulley in front of it. It was secured to a temporary stand held in the bench vice. The plugs were connected up and a hypodermic syringe full of straight fuel was injected into the four induction holes in the heads. The engine started on the second pull of the cord wound onto the pulley but, as expected, it stopped almost immediately as the fuel ran out. This exercise served to give me the spur to carry on with the carburettors and induction manifolds—at least I knew I wasn't flogging a dead horse!

Carburettor and

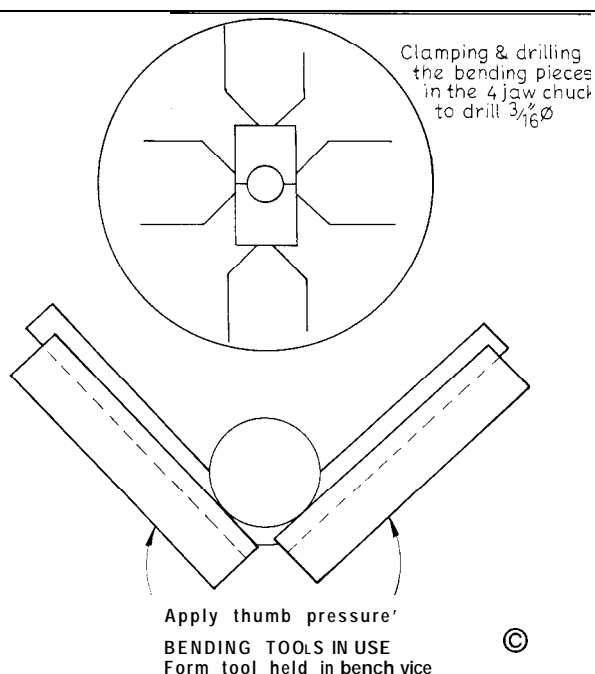
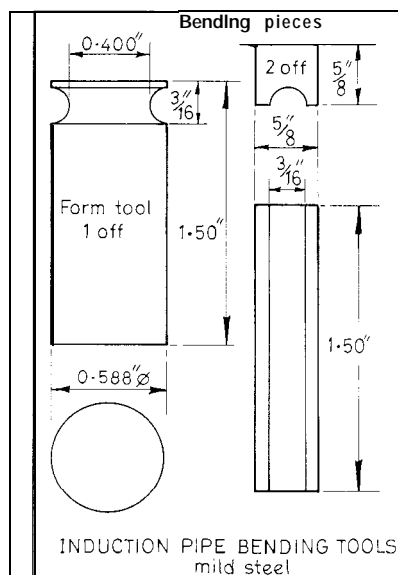
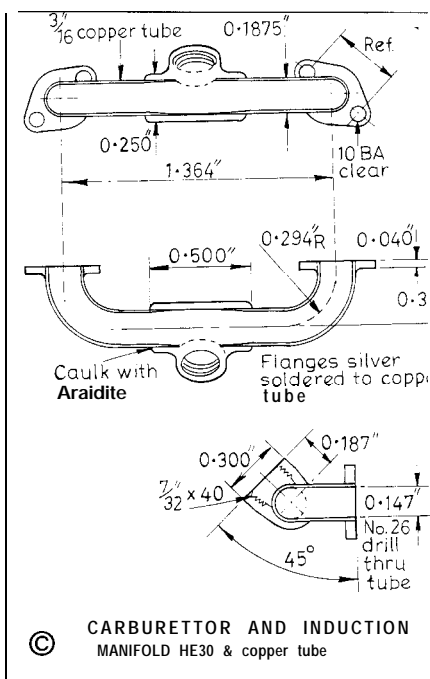
induction manifolds

Manufacture of the manifolds is another rather tedious job, this time involving pipe bending and silver soldering. Probably the best bits to start with are the HE30 aluminium tee-pieces. The drawing shows that they are fairly straightforward items. They are first drilled and tapped in the 4-jaw chuck, the outside diameters can then be partly turned on a mandrel and the unmachinable bits can either be shaped or filed. The 3/16in. I/D should be reamed to take the 3/16in. dia. copper tube which will be stuck into the tee-pieces with Araldite epoxy resin which is both sufficiently strong and heat resistant for this job.

A bending tool, as shown in the drawing, is required to make up the copper bends. I bent my four pipes by hand, just using the three pieces shown, but the copper tube must first be prepared for the bending operation.

Cut four 2in. lengths of the tube and drill each piece through with a No.26 drill. Anneal and fill them with soft solder, making sure that you get all the air out when doing this as an air bubble in the wrong place will allow the copper tube to kink. A kink is unacceptable, not only from the cosmetic point of view but more importantly because manifold turbulence may be caused which would adversely affect throttle control when the engine is running. Four cleanly bent manifold pipes are required. My drawing shows how this can be done by holding the form tool in the bench vice and using the two pieces of half drilled steel to slowly and carefully bend the tube to a right angle. Keep plenty of pressure at or near the form tool end of the two sides of the bend as shown.

Don't be in a hurry to melt out the solder when all four pieces have been satisfactorily bent. It will be needed when cutting and filing the tubes to size and shape. Without the solder they would



be very fragile to work on, so leave the solder there until the tubes have been finally fitted and lengthed ready for silver soldering and caulking with Araldite.

Progress cannot proceed until the induction flanges are made. Made of mild steel, be very careful that all three holes are drilled in the right places to align truly with the studs and induction passageway holes. They should be a close or slightly tight fit on the O/D of the copper tubes,

When you are satisfied that everything will fit correctly according to the dimensions shown on the drawing, melt out the solder from the tubes. I suggest the use of a hot soldering iron for this, not the flame from a propane torch which could easily overheat and burn the work and the solder. If this happens, hard beads of burnt solder, which are almost impossible to remove, may form in the bends of the tubes. These beads would undoubtedly cause turbulent manifold air flow which would result in poor throttle control. Use the hot iron to press the pipe gently onto a piece of wood and draw a piece of knotted string through the tube to clear out all the solder. The outside of the tube can then be cleaned and polished before silver soldering to the flanges.

The flanges are best silver soldered to the pipes by first making four rings of silver solder to a close fit on the copper tubes, and about 0.025in. square in cross section. One of these rings is fitted onto each pipe and the flange fitted. I made my silver solder rings by drilling a piece of 5/16in. dia. mild steel 1/4in. dia. for a depth of 1/2in., holding it vertically in the bench vice and filling the 1/4in. hole with Easiflo No.2 silver solder. Use plenty of flux and try to avoid air bubbles.

When the job has cooled set it back in the lathe, reduce to 0.238in. dia., face off and drill 3/16in. dia. 1/2in. deep. Part off six rings 0.025in. wide. The silver solder swarf can be saved, if you wish by catching it on a piece of clean paper.

Before silver soldering the pipes to the flanges, the latter must be fitted to the head and secured with 10BA nuts. The silver solder rings are

threaded onto the pipes. The pipes can then be assembled to the tee-piece and both pipes and tee-piece assembled to the flanges-a tightish fit is an advantage here. When you are happy that everything is lined up correctly you can remove the 10BA nuts and very carefully remove the whole induction assembly from the head without disturbing the setting of the flanges to the pipes. Remove the aluminium tee-piece and set the pipes one at a time onto a piece of tapered steel for the silver soldering operation.

The end of a piece of 3/16in. dia. steel is turned to a slight taper. This can be pushed firmly into the end of the pipe to help to keep the flange tight on the pipe. Hold this piece of steel in the bench vice with the flange and pipe uppermost, Easiflo flux is put all around the joint and the silver solder ring is pushed down to the flange. The whole job is then brought to temperature dull red-the silver solder will melt and the resulting joint will be perfect. The wire ring will ensure that a uniform amount of solder will be deposited evenly around the joint at the moment of melt. Other than the removal of surface scale, no cleaning up is necessary with this method.

When all four pipes have been silver soldered to the flanges, the tee-piece ends of the pipes can be internally tapered as shown in the drawing, this is a slightly awkward job but is necessary since any discontinuity inside the pipe is just asking for turbulent mixture flow problems later on, I used a 1/4in. dia. centre drill held in a tap wrench to start the tapering procedure to a knife edge, then I used half round needle files and scrapers to smooth further into the pipe.

The two manifolds are completed by fixing everything together with 24 hour Araldite epoxy resin. Thoroughly clean the inside of the tee-pieces and the copper pipes before applying the Araldite to the pipe then insert the pipe into the tee-piece and, with a rotating action, push the pipe into the tee-piece to about the right distance. Fit the other pipe in the same way and assemble the manifold to the head, securing with the 10BA

nuts. Accurately position the tee-piece at an angle of 45deg. to the head, ensuring that the tee-piece is central with the head. This part of the job is best done with the engine completely assembled but without the push rods at least minus those rods which are situated in front of the flanges. Make sure there is a fillet of epoxy resin all around the joint; after curing and fully hardening this fillet can be removed with a modelling knife.

A piece of 7/32in. dia. steel or brass tapped in the lathe 7/32in. x 40tpi, can be screwed into the carburettor hole in the tee-piece and the engine stood on the surface plate. The piece of 7/32in. dia. rod is set truly upright to position the tee-piece at exactly 45 degrees. It will be found that by applying the epoxy resin to the pipe only, there is very little danger of any of it getting into the inside of the manifold and forming obstructions or lumps which would upset the mixture flow. The twisting action ensures that the epoxy resin gets all around the length of the joint. When both manifolds are mounted and caulked with epoxy resin, the two 7/32in. dia. carburettor mounting holes in the tee-pieces must be lengthwise 1/8in. out of line with each other. Final assembly of the induction manifolds to the cylinder heads of my engine was done with thick paper gaskets between the heads and the flanges,

** To be continued.*

Prospective builders are reminded that materials for this engine are available from Woking Precision Models, 10 New Street, Oundle, Peterborough PE8 4EA tel: 01832-272868.

Full drawings for this engine, on two sheets, code P41, are available from Nexus Plans Service, Nexus House, Boundary Way, Hemel Hempstead, Hertfordshire HP2 7ST; tel: 01442-66551; fax: 01442-66998.



V8

Four stroke Aero Engine

Eric Whittle

continues his account of the construction of his little masterpiece with notes on building miniature carburettors before bringing the series to its conclusion with advice on starting and running the engine.

** Part XIV concluded from page 457 (19 April 1996)*

Carburettors

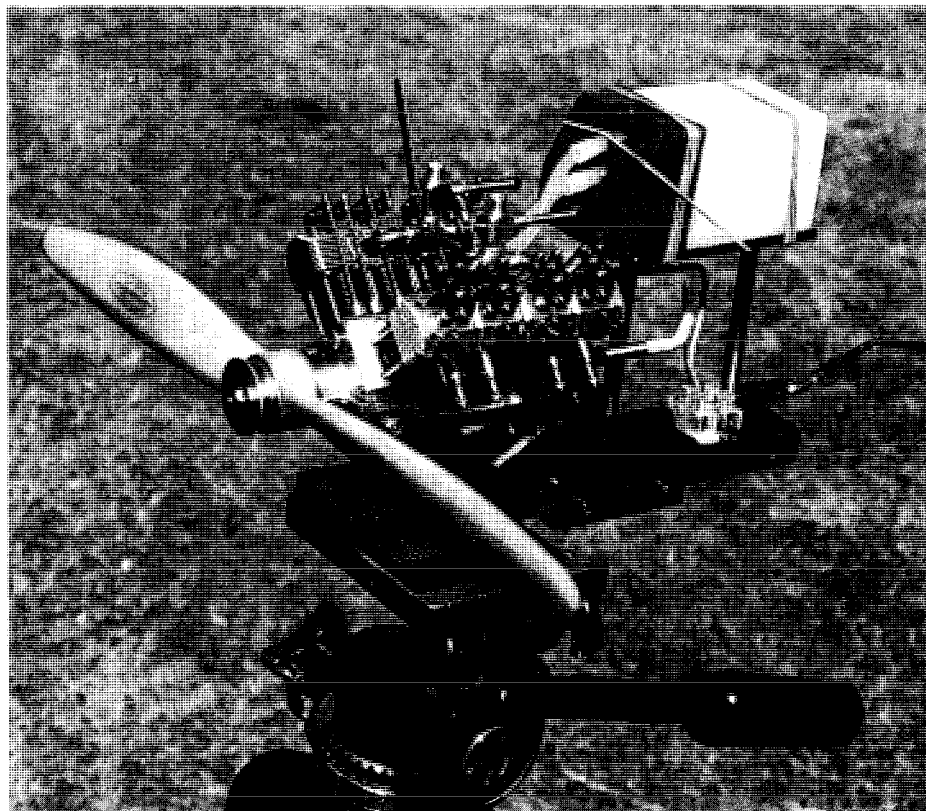
The carburettors are made from pieces of HE30 aluminium alloy. The bodies are fairly straightforward items. All the dimensions are shown on the drawing and need little explanation. The mild steel barrels should be a good smooth fit in the bodies with about 0.002in. of end float. The corners of the bodies can be chamfered or rounded off to improve the finished appearance of the completed carburettors.

The mild steel needle valves must be made so that the 6BA internal thread is truly concentric with the 0.048in. dia. needle. My method of achieving the requisite concentricity was to chuck a piece of 3/16in. dia. mild steel, centre drill and drill 6BA tapping size for a depth of 1/2in., tap 6BA and part off 0.700in. long. A piece of steel was screwcut 6BA for a length of 1/2in., centre drilled and drilled 0.050in. dia. for 1/4 inch. The embryo needle valve was screwed tightly onto this and centre drilled no more than 0.030in. deep with the pilot tip of a 1/8in. dia. centre drill. This was followed by drilling through No.56 to leave the hole slightly less than 0.048in. diameter.

A 2in. length of 18swg wire ground to D-bit form was used to ream the hole to exactly 0.048in. dia. for the needle which was then perfectly concentric with the 6BA thread. After reaming with the D-bit the needle valve holder was carefully turned to the dimensions shown, removed from the screwed spigot and held in a collet to put in 60 serrations by shaping from the saddle using the bull wheel to index. The head could equally well have been knurled.

The needle itself is made by holding a piece of 18swg wire in an accurate collet. A very sharp tool set to dead centre height is used to turn to the proportions shown and the needle is finished by polishing with 1200 grit wet-or-dry paper backed with a 6in. steel rule.

Silver soldering the needles into the holders



must be left until the brass valve bodies have been made. A 0.010in. slitting saw cut is put into the holder as shown.

The fuel valves are made from brass and care should be taken to get the needle valve truly concentric with the valve body. Start by chucking a piece of 1/4in. dia. brass rod with 0.850in. protruding, reduce a 0.400in length to 6BA O/D and screwcut 6BA for 0.350 inch. Use the needle holder as a gauge so that the thread finishes as a snug shake free fit. Centre with the tip of the 1/8in. centre drill and drill No.56 0.575in. deep. Drill a further 0.250in. deep with a No.70 drill and ream with the 18swg D-bit to the bottom of the No.56 hole.

Hold the work piece by the 6BA thread in a collet and complete the rest of the turning and screw cutting to the dimensions shown—it is best to screw cut the 1/8in. x 40tpi thread. The 3/32in. O/D tube is silver soldered into the boss of the body using a similar technique to that when silver soldering the induction pipes. It will be necessary to determine the required angle for the two tubes on final assembly by first screwing the valve body into the carburettor body.

With the valve body completed a decision can be made regarding the position of the needle in the holder. Before silver soldering the needle in place, make a small chamfer on the reamed hole at the top of the holder for a fillet of silver solder thus ensuring a good joint between needle and holder. After soldering, face off the holder and polish the end.

The steel barrels are secured in place with 12BA screws and washers in tapped holes in the carburettor bodies. Position the tapped holes so that the washers overlap the ends of the barrels.

The throttle inserts are made of brass to a light

push fit into the barrels. The venturi curve is formed using another D-bit. 0.070in. dia. is somewhere near right for the minimum diameter, found to be so after much experimenting with different sized inserts although different engines may require different insert diameters. It may be necessary to experiment a little to obtain the best result—the inserts are easy and quick to change anyway. It will be noticed that the output end of the bodies, i.e. the ends which screw into the induction tee-pieces, are well rounded or radiused on the I/D corner to reduce, as far as possible, turbulence which would be caused by the corner being left sharp.

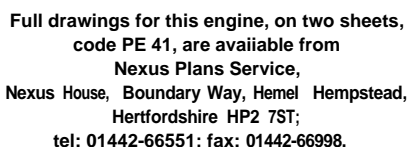
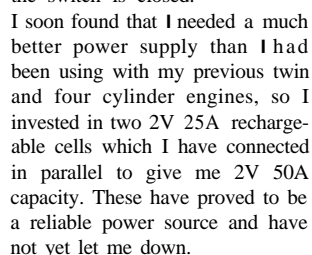
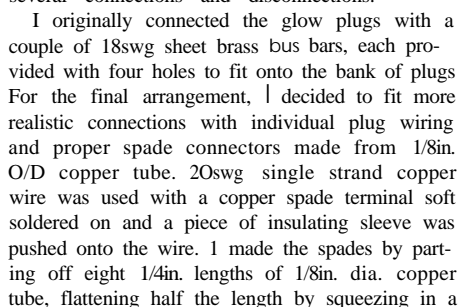
Throttle control linkage

The throttle control linkage will complete the engine to the stage at which it can be started for its first run. Since I intend to fit the engine into a radio controlled model aeroplane in the future, my drawing shows a linkage specially schemed out for push rod control from a rear mounted servo motor but for bench running a simpler linkage could be fitted.

The present carburettor layout is more suited to a model car—carburettors on aircraft always seem to be mounted anywhere but on top as on our little V8. Some further layout changes are planned to site them in a more suitable position by extending from the tee-piece to the rear with copper pipes and positioning the carburettors lower down and somewhere near the timing case. The extra pipe length would have little effect on the induction and throttle control and the result would be a more realistic aircraft engine with an improved servo linkage.

Starting and running the engine.

A suitable running stand will be required to start and run the engine. Something on the lines



When you have the engine running continuously, allow it to warm through before adjusting one needle valve for smoothest running and then adjust the other valve for even smoother running. Be satisfied initially with short runs at varying throttle openings. Due to friction in almost every part of it, you'll find the engine won't run slow at this stage. My own engine wouldn't run at less than 4500rpm in the early running stages and when the oil was drained out after each run it was as black as your hat. After it had clocked up about two hours in many short runs it suddenly became responsive to the throttle control and when the oil was drained it was still the original GTX green colour.

You'll find the engine to be very sensitive to the setting of the needle valves; day to day atmospheric pressure changes will require changes of needle setting. High atmospheric pressure will cause a weak mixture and lean running, low pressure will result in over rich running.

With regard to inverted running of the engine, at the time of writing I have not yet tried this as the sump is charged with 5cc of oil and I am not too sure of the consequences of inverting the engine while running. I feel sure that the engine wouldn't be happy starting or running slow in the inverted position, but it could well be okay at half or full throttle since as at these

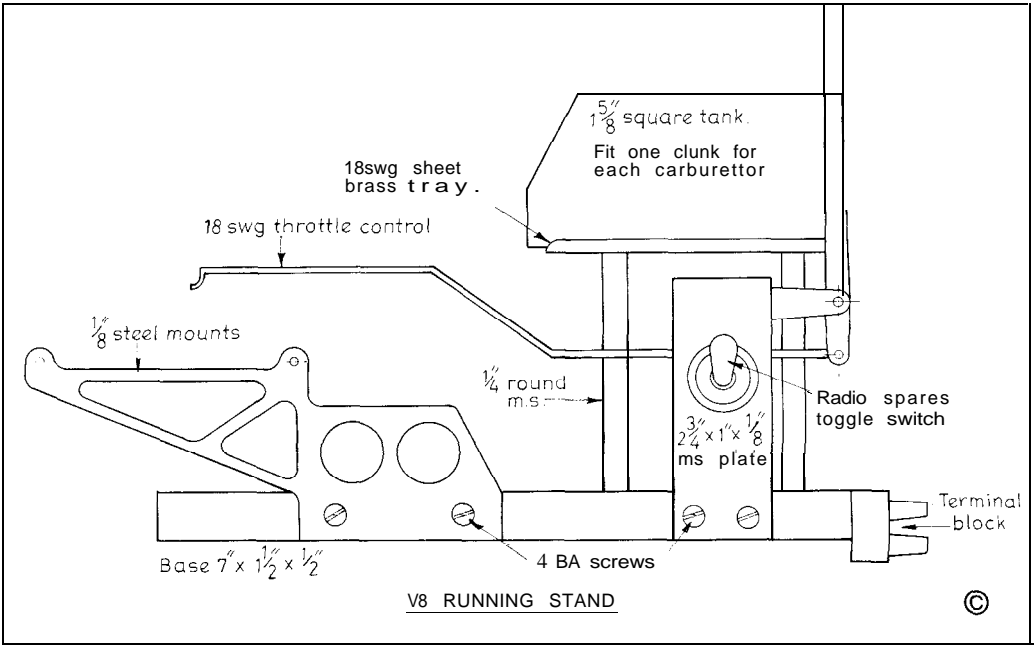
ADJUSTABLE MANDREL STOP

Ivan Sparks in New Zealand devised this useful attachment and hopes that it will assist other lathe users.

Very few model engineers use production-type accessories. Cut-off slides are rare, tail-stock turrets appear seldom and I must say I do not use my 4-way toolpost because it frightens me-it bites! Even so, lathes have carriage locks and the addition of a mandrel stop makes it easy to produce items of consistent length-collars, bushes, studs, spacers, etc. The commonest form of stop is a taper plug with a pin to limit the entry of an item into the chuck jaws, being awkwardly located they are not easily adjusted.

The photographs show an easily mounted and adjusted mandrel stop, capable of quick and accurate multiple settings. The sizes shown are to fit a Myford Super 7 lathe.

Assembled depth stop, with the various adapters in place, posed against the author's lathe.



speeds the entire 5cc of oil would be converted into a mist and gravity would have less effect. I mention this because a friend of mine, who is well experienced in building and flying radio control model aeroplanes, is intending to build a suitable scale model in which to fit and fly the V8. It will be interesting to see if we can get away with a full throttle loop and I am quite optimistic.

I hope my articles over the past year will encourage someone to have a go and build a V8. Even if it isn't fitted into a boat or car or aeroplane, it will be well worth the effort just to see it running on the bench and to hear it purring over at the idle, to say nothing of its value when completed to the running stage. I look forward to hearing through the pages of Model Engineer about the first V8 to be up and running.

Main body

Component A, the main body, consists of two parts, a length of 1/2n. dia. tube and another piece turned from a piece of 25mm mild steel. The tube should have a wall thickness sufficient to take the threads chosen. Two alternatives are available, namely use a fine thread or make and thread mild steel plugs. Half inch tube was used because M12 thread is too coarse for the wall thickness of normal 12mm tube. The choice of thread is often gov-

